THE
ASTROPHYSICAL JOURNAL
AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME XXI JUNE 1905 NUMBER 5

MONOCHROMATIC PHOTOGRAPHS OF THE *ORION* NEBULA

By J. HARTMANN

The thorough investigation of the physical condition and of the motions of the nebulæ is of fundamental importance as well for the understanding of the structure of the universe as for the history of its development. It therefore constitutes one of the principal problems of astrophysical research. But the observation of these objects is generally rendered so difficult by their faintness that it is necessary to employ special methods of observation and apparatus of great light-power; and this is particularly the case when the considerable losses of light due to the spectral dispersion are added. In what follows I desire to call attention to a phenomenon of importance in judging of the constitution of the nebulæ; and it will appear that this has been accomplished with comparatively simple instrumental apparatus.

It is well known that the losses of light in slit spectrographs are so great that, on attaching such an instrument to a large refractor, only a small percentage of the light falling upon the objective of the telescope reaches the photographic plate. The employment of an objective-prism has a decided advantage in this respect; and

therefore I constructed a few years ago an experimental, and hence small, spectrograph of this sort, which was arr nged as follows, with a view to attaining the greatest light-power. The optical parts were made of quartz for diminishing the absorption as far as possible, and their number was kept down to a minimum. The instrument accordingly had only a Cornu 60° prism and as a camera objective a simple quartz lens of the ratio $\frac{a}{f}=\frac{40\,\text{mm}}{320\,\text{mm}}=\frac{1}{8}$. The spherical aberration was overcome by Dr. Steinheil by local retouching.

This small and convenient quartz spectrograph proved, in fact, to have an exceedingly large light-power, particularly for the ultra-violet parts of the spectrum. For instance, a photograph of the nebula *G. C.* 4373, taken with an exposure of 150 minutes, showed fifteen lines of the nebular spectrum, while plates taken with the same exposure with the slit spectrograph attached to the great 80-centimeter refractor never recorded more than four lines. Plates of the *Orion* nebula taken with this apparatus, however, yielded a particularly interesting result; for they indicated that the different parts of the nebula emit light of different composition, and that extensive areas of characteristic form shine almost solely with ultra-violet light of the wave-length 3727.

The different monochromatic images into which the light of the nebula is separated by the objective-prism are, of course, very small, on account of the short focus of the camera lens: 1 mm on the plate corresponds to an angle of nearly 10′. This size was, nevertheless, sufficient to permit the form of the nebula to be distinctly recognized. While the images corresponding to the other lines of the spectrum were about alike, the image produced by the rays of the wave-length 3727 differed strikingly from them, extending out beyond the range of the other images by more than 10′, with intense and well-marked portions. At first glance it seemed as if the nebula had an entirely different form in the light of λ 3727 than in the light of the other colors; and it is only on minute examination that on long exposures an indication of the regions mentioned can also be detected in the light of the other lines, particularly of the two principal nebular lines, N_1 and N_2, at λ 5007 and λ 4959. In any case, the intensity of the rays of λ 3727 predominates so greatly that one may speak of an almost monochromatic ultra-violet light of the area in question.

So conspicuous a phenomenon could not have been wholly undetected in the very numerous earlier observations of the spectrum of the *Orion* nebula. Huggins,[1] who in 1882 first proved the existence of λ 3727 in the spectrum of the *Orion* nebula, as well as Campbell, who has made the most extensive studies on this spectrum, employed slit spectrographs. Hence they were able to reach conclusions only as to the spectrum of the small strip, the image of which fell upon the slit during the exposure. This strip had a length of 2′.5 on the plates of Huggins, and therefore contained a cross-section through the brightest part of the nebula, the so-called Huyghenian Region. Campbell's plates, for which the slit included an angle of about 7′, did not reach to the ultra-violet branches I have observed, which are more than 10′ distant from the trapezium. For the same reason the other observers who have used slit spectrographs have noted nothing of the phenomena.

The conditions were more favorable for observations made with the slit spectrograph, of which I will mention here the two following. In 1888 and 1890 W. H. Pickering made two photographs of the *Orion* nebula with the use of the objective-prism, which he describes in the *Annals of the Harvard College Observatory*, **32**, Part I, p. 75. He remarks that the line at λ 3727 was especially intense "along the southeast border of the Huyghenian Region, also in that part just west of the trapezium." According to this statement, the places remarked by Pickering lie close to the Huyghenian region, so that it would be hardly possible to identify them with the ultra-violet area observed by me. But the statement of Mitchell[2] as to the spectrum of the *Orion* nebula photographed by him directly with the concave grating of 60 cm focus accords well with my observation. He says: "The violet line λ 3727 has the greatest extent. The faint outlying regions show in this line a greater intensity and a greater extent than in $H\beta$. The Huyghenian regions appear about equally intense in λ 3727 and $H\beta$ . . . . " There can accordingly be no doubt that Mitchell also saw certain parts of the nebula solely in the light of λ 3727, although he gave no more precise statements as to their position. After I had established beyond a doubt the presence of these ultra-violet portions of the nebula, by several photographs

[1] *Proc. R. S.*, **33**, 425, 1881. [2] *Astrophysical Journal*, **10**, 34, 1899.

taken with the quartz spectrograph, I sought for some other way of determining more accurately their form and position and of following up the phenomenon further. I found a very suitable procedure for these investigations in the use of color filters with direct photographs of the nebula.

The employment of ray filters for astronomical purposes has been repeatedly suggested for the particular object of obtaining sharp pictures with a refractor achromatized for the visual rays. Lohse[1] reported on such plates in 1886. Similarly Spitaler[2] in 1890, and in 1900 Ritchey[3] made beautiful pictures with the great Yerkes refractor according to this method. The only attempt to use a color screen for investigating the relative intensities of the different spectrum lines in the *Orion* nebula was made by Keeler in 1899 with the Crossley reflector of the Lick Observatory.[4] He made, on the one hand, a photograph on an orthochromatic plate through a filter which transmitted only the first two nebular lines and $H\beta$, and, on the other hand, a photograph on an ordinary plate without a filter. From the comparison of the two plates he drew the conclusion that the light of $H\gamma$ and the other hydrogen lines (consequently also of $H\beta$) must be more intense than that of the two nebular lines N_1 and N_2 at those portions of the nebula which were impressed with a greater relative intensity on the second plate. This conclusion is, however, not valid, as is indicated by my plates presently to be mentioned, since the great photographic brightness mentioned by Keeler is not due to the light of $H\gamma$, but to the line λ 3727. But, as I desire expressly to point out, this error is without significance in respect to the fundamental idea of Keeler's investigation, namely, the proof that the light does not have the same spectral composition at all portions of the nebula.

For photographing through filters, the spectrum of the nebula may be divided into three sections, the first of which embraces the three lines of N_1, N_2, and $H\beta$—consequently the total light effective in visual observations. The second section extends from $H\beta$ about to the wave-length 3900 or 3800, and contains the series of hydrogen

[1] *Astronomische Nachrichten*, **115**, 1, 1886.

[2] *Annalen der k. k. Sternwarte in Wien*, **7**, 202.

[3] *Astrophysical Journal*, **12**, 352, 1900.

[4] *Ibid.*, **9**, 133, 1899.

lines. In the third section, beyond λ 3800, lies the ultra-violet λ 3727 as the only conspicuous line. We may disregard the few other lines additional to those mentioned here also occurring in the spectrum of the *Orion* nebula, on account of their extremely slight intensity; and we may similarly neglect the faint continuous spectrum of the nebula.

I have attempted to produce filters which should be as transparent as possible for each one of the three sections, while they should wholly absorb the other two; and after extensive experiments I have adhered to the following, which accomplish the desired purpose very well and can readily be obtained anywhere.

1. *Filter of picric acid.*—An unexposed photographic plate is first fixed, and then bathed for several minutes in a concentrated solution of picric acid. The gelatine film assumes a very intense yellow color, and completely absorbs all the wave-lengths shorter than λ 4800, while it transmits the longer wave-lengths, hence especially the lines N_1, N_2, and $H\beta$, almost without loss.

2. *Filter of quinine-cobalt.*—A gelatine plate is similarly bathed in sulphate of quinine and used in connection with a blue cobalt glass. This combination transmits quite well the spectral radiation between λ 3880 and λ 3740, and absorbs all other rays.

3. *Nitroso-filter.*—If a gelatine plate is bathed in a concentrated solution of nitroso-dimethyl-anilin, it takes on a yellow color almost exactly like that of the picric acid screen, but it differs very decidedly from it in its absorptive action. Red, yellow, and green portions of the spectrum are transmitted almost without loss. Absorption begins at λ 5050, and then increases rapidly so that the absorption is complete even at $H\beta$; the lines N_1 and N_2, although very greatly weakened, are still transmitted. The heavy absorption extends to λ 4000; from there on the transparency increases rapidly, and λ 3727 is again well transmitted. The low transparency of this filter for N_1 and N_2 can be made harmless by using for those photographs a kind of plate which is not sensitive at this point; while contrariwise for the photographs used with the picric acid filter, plates are chosen which are as sensitive as possible in the blue-green.

By the simultaneous use of the first and third filters, photographs can also be obtained on which only N_1 and N_2 are effective, $H\beta$ being shut out.

I have employed these filters in securing a series of photographs of the *Orion* nebula with a Steinheil mirror of 24 cm aperture and 90 cm focus. The unfavorable weather which has prevailed during the latter months of the winter prevented me from carrying out the research to the full extent that I had planned; using every opportunity for observation that was in any way available, I was able to get only the following plates in two months.

Plate	Date	Filter	Exposure
3.....	1905, Jan. 23	Nitroso	45 minutes
5.....	" 25	Nitroso	120 "
7.....	Feb. 13	Quinine-cobalt	30 "
8.....	" 13	Picric acid	7 "
9.....	" 26	Picric acid	120 "
10.....	" 27	Quinine-cobalt	56 "
11.....	" 28	Quinine-cobalt	10 "
12.....	Mar. 1	Quinine-cobalt	60 "

The sky was entirely clear only on January 25; on all other evenings mists arose and disturbed the observations, as is shown by the very short exposures in some instances. These few plates have, nevertheless, already led to several interesting results, which I would point out in connection with the accompanying reproductions. Plate XX is a sixfold enlargement of photograph No. 5 taken with the nitroso-filter. Plate XXI is an enlargement of photograph No. 9 taken with the picric acid filter. The sketch in Fig. 1 makes no attempt to accurately represent the appearance of the nebula, but is only for facilitating the identification of the regions referred to. The scale of the three figures is 1 mm = 40″.

We should note, in the first place, the extraordinary intensity of the line λ 3727 in *all* parts of the nebula. Photograph 5 (Plate XX), taken with two hours' exposure with the nitroso-screen, gives an image of the nebula 45′ in diameter, in which a great number of details of structure can be recognized. This ultra-violet light is also the principal emission of even the most outlying and faintest portions of the nebula, which are mostly lost in the reproduction. I also got the impression that the condensations of the nebulous mass which give the *Orion* nebula its peculiar appearance of motion are most sharply represented in the ultra-violet light, while the light from the hydrogen lines seems rather to form a uniform background.

PLATE XX

THE *ORION* NEBULA
Monochromatic Photograph with Light of Wave-Length 3727

PLATE XXI

THE *ORION* NEBULA
Photographed with Light of the Lines N_1, N_2, and $H\beta$

Along with this general diffusion and intensity of the ultra-violet light, by which it is possible to obtain a complete photograph of all parts of the nebula through the nitroso-screen, this light also comes out with particular intensity at certain places. In this respect, the most interesting illustration is shown in the case of the series of strips

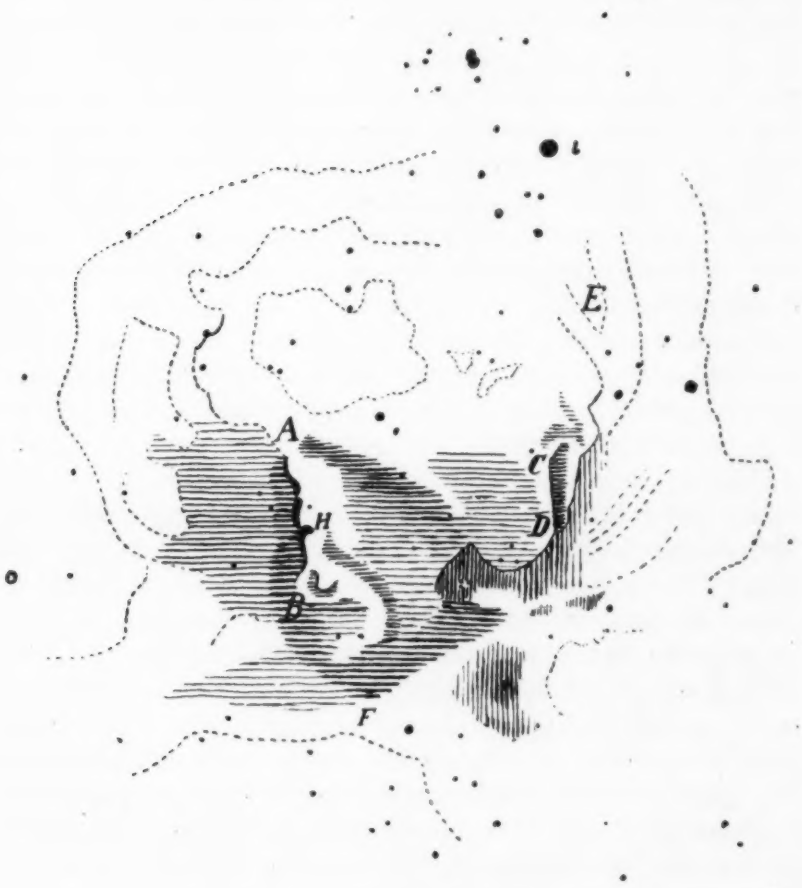


FIG. 1.

shaped like arcs, 14′ west of the trapezium, designated in the drawing by *AB*, which constitutes the ultra-violet portion, earlier discovered with the quartz spectrograph. In this section the light of the lines N_1 and N_2, as well as of the hydrogen lines, is so faint that this area

is entirely invisible to the eye, although it constitutes one of the most striking objects on every plate taken with the reflector. As stated above, Keeler erroneously ascribed the light of this region to the hydrogen lines, hence particularly to $H\gamma$.[1]

The second region obtained by Keeler on his plate with the Crossley reflector, the strip marked *C D*, parallel to the *Proboscis Major*, *D E*, similarly does not shine with hydrogen lines, but in that of λ 3727. It is so intense that this region on the plate taken with the nitroso-filter looks entirely different from that on the drawings of the nebula representing visual observations, and also from that on plates taken with objectives, which, of course, always absorb the ultra-violet light strongly. On refractor plates the *Proboscis Major*, *D E*, is always striking, having its sharpest boundary on the western side; and it constitutes a characteristic form particularly at the slight curve surrounding the star Bond 784 at *D*, while Keeler's strip *C D* is hardly visible. But in the ultra-violet light this strip is quite as bright as the most intense portions of the *Proboscis Major*, and at *D* mingles with the latter to such an extent that the star mentioned is entirely overpowered.

The two regions mentioned, *A B* and *C D*, are very faint in the light of the nebular lines N_1 and N_2, as appears from Plate XXI; but they are nevertheless still fainter in the light of the hydrogen lines. The small condensation at *H* is particularly bright in the ultra-violet light; it is hardly suggested on the photographs through the quinine-cobalt filter, while the stars Bond 373 and 382 north of it, which are wholly overpowered by the nebula on Plate XX, come out very distinctly.

I have indicated on my sketch by heavier horizontal shading the other portions of the nebula which are conspicuous for their ultra-violet radiation. As may be seen, they are principally exterior portions of the Huyghenian region, particularly the arc-shaped northern boundary which extends toward *F* from the trapezium, as well as a streak extending from the trapezium toward *A*. The ultra-violet light seems also to predominate in the portion of the nebula indicated by dots. I have not yet, however, been able to determine to what degree this is the case, as I have not yet had a

[1] *Astrophysical Journal*, **9**, 142, 1899.

chance to make sufficiently long exposures in the light of the *H* lines with the quinine-cobalt filter.

I will here briefly call attention to two other phenomena. First, the light of the lines N_1 and N_2 is almost wholly lacking in the nebula *G. C.* 1180 (*V* 30) which surrounds the star *c Orionis*, 35′ north of the trapezium. Hardly a trace of the nebula appears on the plates made through the picric acid screen even with two hours' exposure (see Plate XXI), while it is beautifully depicted on the other plates, especially with that taken in ultra-violet light (Plate XX). The light of the hydrogen lines is also rather bright in this nebula, whence its easy visibility to the eye in spite of the faintness of N_1 and N_2.

The second remark refers to the intensity of the star disks, which display marked differences in certain cases for the different filters. Thus hardly any traces of many of the stars appear even on the two-hour exposure (No. 5), which are impressed on photograph No. 8 in the green part of the spectrum with an exposure of only seven minutes. I will cite here as examples only the stars Bond 402 and 430. I shall later undertake the complete enumeration of such objects when there is available for the middle section of the spectrum as good a photograph as I have for the exterior portion of the spectrum. When these stars lie in the nebula itself, it is difficult to decide with certainty whether the apparent difference in brightness is not principally due to the photographic concealment of the star image by the nebula. This question could be easily decided by a repetition of the filter plates with an instrument of longer focal length. For the stars lying without the nebula, we probably can explain the different intensity on the different filter plates only as an effect of the type of the spectrum. The assumption made hitherto—that the faintest stars in the neighborhood of the *Orion* nebula also belong to the first type, as is the case for the brighter ones, the spectra of which have been investigated—is now fully confirmed in a general way by the photographs through the color screens, since the ratios of intensity agree for nearly all the stars in the visual (Plate XXI) and in the ultra-violet portions (Plate XX) of the spectrum. The few stars which are depicted in greater relative intensity through the picric acid filter may be assumed to belong to the second or even the third spectral type.

The observations here communicated thus confirm anew, first, the fact, suspected by Huggins and later proved beyond a doubt, particularly by Campbell, that the light of the *Orion* nebula is not homogeneous, but of different composition in the different regions. The conclusions which have hitherto depended upon the different behavior of the nebular lines N_1 and N_2, as compared with hydrogen lines, are now extended also to the line $\lambda 3727$. According to all previous estimations, the ratio of intensity of the lines N_1 and N_2 is constant in all nebulæ, and also in the different parts of the *Orion* nebula, as was established with the greatest certainty by the measurements of Wilsing and Scheiner.[1] If the conclusion should be drawn from this that these two lines belong to the spectrum of the same gas; and if it is rendered probable from the varying ratio of intensity from that of the hydrogen lines that this gas is different from hydrogen; then it is now proven, by the still different behavior of the intensity of the line $\lambda 3727$ from that of the two groups of lines just mentioned, with an equal degree of probability, that there occurs in the nebulæ at least a third gas, additional to the other two, partly mingling with them, but also partly separated in space from them. It is not very likely that this third gas is oxygen, which has a rather strong line at $\lambda 3727.5$, while the best determination, by Wright,[2] yielded the value $\lambda 3726.4$ for the wave-length of the nebular line. Inasmuch as this determination is, however, not yet very accurate, it would be desirable to have the wave-length of the two lines determined as sharply as possible.

It has already been repeatedly pointed out, and it is confirmed ánew by the observations here described, that it is an essential condition for the proof of any changes or motions in a nebula that only photographs of the object in question taken under precisely similar conditions should be compared. Ray filters are of the greatest value just for securing these constant conditions, since they render harmless all the sources of error due to the color sensitiveness of the brand of plates used for the photograph, as well as the selective absorption of the optical parts of the instrument and of the atmosphere. For example, if plates having almost the same curve of

[1] *Astronomische Nachrichten*, **159**, 181, 1902.

[2] *Astrophysical Journal*, **16**, 53, 1902.

sensitiveness are exposed through the nitroso-filter, and are developed to an equal density, then they are directly comparable; such a comparison, which may be made with the Zeiss stereocomparator, will lead, though perhaps not for some decades, to the determination of the motions taking place in the nebulæ, which are up to the present wholly unknown.

ASTROPHYSIKALISCHES OBSERVATORIUM,
Potsdam, March 24, 1905.

HIGH-TEMPERATURE RADIATION

By P. G. NUTTING

Stellar spectra bear a striking resemblance to the spectra of gases conducting an electric current in the form of an arc, spark, or vacuum-tube discharge. Yet we can hardly conceive of an excitation of radiation that might be common to stellar and arc spectra. Nor can we imitate stellar spectra by mere thermal excitation; at least not by merely heating an elementary substance up to 1,500°. Hence it would appear that the radiation of a body at the higher stellar temperatures is quite a different process from the radiation from a body at a temperature of 1,000° to 2,000°. And although the manner of excitation may be quite different, the processes of radiation at very high temperatures appear to be essentially the same as those involved in the radiation from an arc or Plücker tube. It is the purpose of this investigation to examine in detail the processes involved in the electrical, mechanical, and thermal excitation of radiation, and, on the other hand, to trace back lined spectra and black-body spectra to a system of radiators consistent with the electromagnetic theory of radiation, and with the atomic and kinetic theories of the structure of matter. Many of the conclusions reached are, of course, only tentative at best, since direct experimental tests are beyond our facilities, and astrophysical evidence is too meager to be conclusive.

RADIATION PROCESSES INVOLVED

We are here concerned with the transformation of mechanical, electrical, and thermal energy into the energy of radiation, and are to determine under what conditions and within what limits these three forms of excitation may produce similar radiation of a given character. So far as spectroscopic evidence alone is concerned, it must be admitted that the problem is indeterminate. Sufficient conditions (for radiation) far outnumber the necessary conditions; many different forms of radiators might give the radiation observed. Nor can the electromagnetic theory of light and of the dynamics of moving charges of itself furnish a sufficient number of independent

sets of conditions to make the problem determinate. The atomic theory of matter and the theory of electrical conduction are inadequate as well. But all four sets of conditions taken together appear to supply sufficient independent data to make the problem determinate.

Electromagnetic theory indicates that electromagnetic radiation must originate in an electromagnetic disturbance of some kind; that is, in a variable electromagnetic field, either a stationary field varying in intensity or a steady field in motion with a variable velocity. This is a *necessary* condition. Larmor, Lorentz, Heaviside, and others have even calculated the rapidity of variation or the amount of acceleration necessary to produce a given amount of radiation of a given character. A constant field does not lose energy, nor can the motion of an uncharged, unmagnetized body through such a field cause radiation; much less could the motion of such a body *not* within such fields.

The atomic theory with the kinetic theory of gases supplies evidence for the existence of moving particles having the necessary dimensions, elastic constants, and degrees of freedom. The modern theory of electrical conduction indicates that these moving particles carry electrical charges of certain amounts in a given manner. The combined evidence is then that atoms and molecules are neutral aggregates of charged particles whose individual motion originates electromagnetic radiation. Now, spectroscopy shows that the emission of lined spectra, of black-body spectra, and of many intermediate forms, are to be accounted for. To do this consistently with the atomic theory, the electromagnetic theory, and the theory of electrical conduction, it is necessary and sufficient that there be present in a radiating body one or all of the three following types of radiators:

(1) Neutral aggregates of charged particles—atoms, molecules, or groups of molecules, in general all three—possessing a motion of translation and, in general, rotatory motion about some axis. Neither motion is directly concerned with radiation. When undisturbed from without, such neutral aggregates would so arrange themselves as to have no external field, and hence would not start electromagnetic waves, whatever their motion of translation or rotation. But disturb the equilibrium of the arrangement—by a violent impact with a

neighbor, by bombarding it with charged particles having a very high velocity, or by sending past it a sharp electromagnetic wave or pulse—and it will possess a temporary external field; this external field, alternating as the aggregate oscillates through its equilibrium formation and regains its original steady state, will start electromagnetic waves. Rings of negative electrons rotating about or within a positive kernel, forming such systems as have been discussed by J. J. Thomson and Nagaoka, would be possible types of this class of aggregates.

(2) Aggregates electrically neutral or not, as to total charge, but with parts relatively so widely separated, so few in number, or so arranged that there is considerable local field. Such an aggregate need but to rotate to produce an alternating field, and hence send off an electromagnetic wave. A system having a structure like the solar system, or like the hydrocarbon molecule imagined by chemists, would be typical of the class of aggregates.

(3) Free charged particles torn from the neutral aggregates of classes (1) and (2), and moving independently. These charged particles possess an electromagnetic field, and radiate when this field changes, i. e., when the velocity is changed. The amount of radiation is proportional both to the velocity and to the acceleration. Impact and orbital motion would be the chief causes of acceleration.

Radiation from aggregates of class (1) would be due to the rapid oscillatory motion, radial, transverse, or tangential, of the charged parts of the aggregate, and hence would be characterized by a definite period. Stronger excitation would produce more intense radiation without affecting the period. This period would be very small, on account of the great forces involved in such stable equilibrium, and would have an upper limit rather sharply marked. On the other hand, radiation from sources of the second class, depending on central acceleration, would vary in period with each impact. The various periods radiated would be distributed about a mean, which would depend upon the average rotatory energy before collision and upon the velocity of impact; i. e., it would vary with the temperature. Sources of the third class would be relatively of little importance in producing ordinary radiation from a gas—except when intense electric currents are concerned—on account of the

relatively small number present and the rapidity with which recombination takes place. In metals they are much more numerous, and appear to play an important rôle in radiation. The radiation caused would of course—like that from sources of class (2)—have no definite single period.

Having traced radiation back to three possible sources consistent with kinetic theory, spectroscopic phenomena, and the theory of electrical conduction, let us consider the various means, mechanical, electrical, and thermal, of exciting these sources to radiation. The process of breaking up a neutral aggregate into parts not neutral we shall refer to, for short, as *ionization*, the charged parts being called ions; in chemical ionization the parts are of the same order of magnitude, while electrical ionization is a tearing away of one or more of the smallest charged particles of which the neutral aggregate is composed. On the convection theory of electrical conduction, conductivity of course *implies* an ionized state of the conductor. A measurable conductivity requires that something like one molecule in 10^{12} be ionized, while a conducting gas gives sufficient luminous radiation to be perceptible when about one molecule in 10^{7} is ionized, and experiment shows that the luminosity increases in proportion to the current, i. e., in proportion to the number of molecules ionized. Luminosity appears to be always accompanied by ionization, i. e., by electrical conductivity, even in cases of fluorescence. A study of electrically excited gases indicates that recombination is the chief cause of the violent agitation of the aggregates of class (1) above which radiate lined spectra.

ELECTRICAL EXCITATION

Application of a steep potential gradient to a gas pulls the oppositely charged parts of neutral aggregates in opposite directions, and if the gradient be great enough, it will ionize the gas and allow a current to pass. In the steady state the rapid recombination is balanced by fresh ionization, caused chiefly by the bombardment of neutral aggregates by the convection of charged particles—positive and negative ions—constituting the current. The energy necessary to ionize a molecule may be calculated from the fall of potential—about 5 volts for air, hydrogen, and helium—through which a charged

particle must run in order to gain[1] sufficient impetus to ionize a molecule by impact. $E=(V_2-V_1)e=5\times10^8\times1.1\times10^{-20}=5.5\times10^{-12}$ erg per molecule. This is 3.3×10^8 ergs, or 7.8 calories per cubic centimeter of gas at 0° and 760 mm, and appears from the work of Davis (*loc. cit.*) to be very nearly the same for the different elementary gases, but considerably—50 per cent.—greater for a compound gas like CO_2. Reduced to mass units, 7.8 calories per cubic centimeter is for air 6,000 calories per gram, and for other gases in inverse proportion to the atomic weight. This is an amount of energy approximately 100 times that required to vaporize air, and eleven times that required to vaporize water.

If, then, an ionization of one molecule in 10^7 be required to render a gas visibly luminous, this would require an expenditure of 10^{-5} ergs of electrical energy to excite to visible luminosity sources of lined spectra—class (1) above. In a metal the permanent conductivity indicates permanent ionization, while the character of the radiation indicates that it comes from sources of classes (2) and (3). Now a metal becomes visibly luminous when radiating energy at the rate of about 3 watts per square centimeter of surface. Hence, assuming a molecular diameter of the order of 10^{-7} centimeters, we would have 3×10^7 ergs radiated by 10^{14} molecules, or 3×10^{-7} ergs per molecule. If all the radiation were luminous, instead of less than 1 per cent., only about 10^{-9} ergs per molecule would be required to excite luminosity in a (solid) metal. This is less than a thousandth part of that required to ionize and render luminous a molecule of a gas or vapor.

The ionization in a metallic solid appears to be largely due to the proximity of the molecules, causing an overlapping of adjacent electromagnetic fields; a weakening of internal conservative forces, or an overbalancing of internal by external forces, however we choose to regard the process. Probably the nearest analogue is the solution of a salt in water. The radiation from a highly compressed gas would, of course, take on more and more the character of the radiation from a heated solid, as the molecules are forced nearer and nearer together; that is, radiators of the first type would become radiators of the second and third types. Hence the assumption of

[1] B. Davis, *Phys. Rev.*, **20**, 145, March 1905. Townsend, *Phil. Mag.*, (6) **1**, 209, Feb. 1901.

a damping mechanism is by no means necessary to account for the broadening of optical spectral lines and the emission of a continuous spectrum.

A metal of course loses its ionization on being vaporized, for a metallic vapor is no more a conductor than hydrogen or air until it is ionized. The energy required for ionization would make the heats of vaporization of metals low, and thus is an important factor in solar and stellar phenomena.

There is a third form of electrical excitation, namely, that caused by the passage of an electromagnetic wave or pulse, like optical or Röntgen radiation. Such a wave or pulse would of course tend to jerk apart positive and negative charges. But a simple calculation shows that to impart 10^{-5} erg to a molecule would require a wave of such short period, or a pulse so thin, as to be beyond the limits one could assign to ultra-violet and Röntgen radiation. But when a gas is just at the point of being ionized by other means, these forms of radiation are undoubtedly important factors in helping to complete the ionization.

MECHANICAL EXCITATION

Mere translation through space would be sufficient to ionize a body, and hence produce intense radiation, provided the velocity be great enough. From the dynamics of moving charges we know that if two electric charges are moving together, the electric forces acting between them are opposed by the magnetic forces arising from their motion. The expression for the resultant electromagnetic force between the two charges always contains the factor $1-u^2:V^2$, in which u is the velocity of the charges and V the velocity of light, whatever their orientation. Hence, when moving with the velocity of light, any aggregate of particles, neutral or otherwise, held together by electrical forces, would become unstable. A neutral aggregate broken up by this means would thus become a group of separately moving charged particles, hence would lose—and absorb—energy at a tremendous rate, would recombine as a radiator of type (1), and would therefore give off intense optical radiation of definite period. The energy required for such mechanical ionization—$\frac{1}{2}m\,u^2=\frac{1}{2}(2\times10^{-23})\ (3\times10^{10})^2=10^{-3}$ erg per molecule—is a thousand times as great as that required for ionization by other—e. g., elec-

trical—means, hence we should look for ionization of this class only in stellar explosions and the like. The radiation from *Nova Persei* may well have been due to mechanical excitation of this type.

Given the Maxwell-Boltzmann distribution of the velocities of the molecules of a gas, and assuming that this distribution-curve is displaced toward higher velocities at higher temperatures, one might expect a few molecules at high temperatures to attain ionizing velocity. But calculation shows that a temperature of millions of degrees would be required—a temperature far greater than that sufficient to ionize the gas by other means discussed in the following paragraph.

THERMAL EXCITATION

Heating a body, say a gas, would tend to ionize it, and hence cause it to radiate by each of two processes; heating would increase mean molecular velocity, and hence violence of impact, and it would increase internal molecular energy, and hence weaken internal conservative forces. Let us calculate the temperature at which the mean molecular energy is equal to the energy (page 5) required to ionize a molecule by electrical means. Specific heat is sufficiently independent of temperature[1] for our purpose, and may be taken as about $\frac{1}{4}$ calorie per gram. This is about 2×10^{-16} erg per molecule per centigrade degree. Hence, at a temperature of $(5\times10^{-12}\div 2\times10^{-16}=)2.5\times10^{4}$ degrees absolute, a body would possess sufficient internal energy to completely ionize it. It would possess sufficient energy to be ionized sufficiently to be intensely luminous at a much lower temperature—about 2,500°—if the distribution of molecular energy about the mean is anything like that given by the probability function.

Assuming then only the equivalence of thermal and electrical energy, and taking the value—5.5×10^{-12} erg per molecule—for the energy of ionization obtained by electrical methods, we may draw two very important conclusions. First, that at a temperature of about 3,000° every body, even a pure isolated gas, should become luminous. Secondly, there is a fixed upper limit—about 10,000°—to the temperature to which it is possible to heat a body. It could not be heated electrically to a higher temperature, because there would

[1] Holborn and Austin, *Sitzungsberichte der k. p. Akad. d. Wiss. zu Berlin*, Feb. 2, 1905.

be no more ions to carry a greater current, nor heated thermally, on account of the tremendously rapid loss by radiation as well as the limit to the rate at which thermal energy could be conducted to the body. We may speak of this roughly defined upper limit to temperature as the *ionization temperature*, just as we speak of the temperatures of vaporization and of fusion.

Let us examine the possible effects of chemical combination on ionization temperature and luminosity. If the combination is exothermic, and the process is *continuous*, as in a flame, the extra heat liberated would of course depress the ionization temperature, and thus the temperature at which luminosity occurs. But if the compound gas forms an isolated body and is merely heated, or if it is conducting an electric current, ionization and recombination occur alternately, and on the whole as much energy will be absorbed as liberated. However, another effect comes in which *would* depress the ionization temperature; namely, the weakening of internal forces by the proximity of aggregates discussed above. This effect would depend upon molecular and atomic mass and structure, rather than on the energy of combination, and, like excessive compression or condensation, would depress the ionization temperature in every case.

The relation of spectral radiation to black-body radiation cannot be discussed here, but, applying the laws of black-body radiation to solar and stellar radiation, as a first approximation, we find strong evidence of the existence of an ionization temperature; that is, there appears to be a fixed upper limit—of about 7,000° to 10,000°—to temperature which is not exceeded by any star. Further, the similarity of stellar spectra to the spectra of gases conducting an electric current is just what would be expected if the mechanism of radiation be that here discussed. Further, Nasini and Anderlini[1] have succeeded in obtaining the red end of the nitrogen spectrum by merely heating pure nitrogen to a temperature of about 3,000°. Liveing and Dewar,[2] King,[3] and others, by vaporizing various metals at a similar temperature, have obtained lined spectra, but the possibility

[1] *Rend. ac. dei Lincei*, (5) **13**, 59–66, 1904.

[2] *Proc. R. S.*, **34**, 119, 1882.

[3] *Annalen der Physik*, **16**, 360–382, Feb. 1905.

of chemical changes occurring at the same time was not excluded, hence the excitation of the spectral radiation observed might not have been directly due to purely thermal causes.

The word "temperature" has been used in this paper in its thermodynamic sense, as the argument of the energy-content function, rather than in its kinetically defined sense. The ordinary kinetic theory of course does not hold for any ionized body, that is for any body which is a source of radiation of an electromagnetic nature. If, then, the application of the notion of temperature to heated solids —containing radiating sources of types (2) and (3)—be logical and useful, why should it not then be as applicable to incandescent gases containing sources of the first type as well as of the second and third? I do not see that the greater rate of loss of energy by radiation, or the limitation of this radiation to a few periods, presents any essential difficulties to the rigorous definition of energy-content. Jeans[1] has extended the kinetic theory to cover a sort of generalized molecule having n degrees of freedom of one class and r of another class, and subject to dissipative forces, but the limits to the thermodynamic definition of temperature permit a still more general kinetic theory. We might have not one, but several kinds of moving particles possessing electromagnetic as well as mass inertia, subject to elastic and dissipative forces of any nature. The seat of this energy may be partly in the adjacent field, as well as within the particles. So long as the heterogeneity does not extend to the mean direction of motion of the particles, so long as a vector definition of energy and temperature is not required, we shall have no difficulty in constructing a thermodynamic definition of temperature. But in a gas conducting an electric current, there is such heterogeneity even in finite regions, that rather than to attempt an extension of the term "temperature" to cover this case and the case of gases so rarified that the free path is of finite length, it would appear advisable to limit the use of the term to bodies possessing only infinitesimal heterogeneity of distribution of energy; that is, to cases to which statistical methods are applicable.

SUMMARY OF CONCLUSIONS

Electromagnetic radiation may originate in material bodies when

[1] *Phil. Trans.*, **196**, 397–430; May 22, 1901.

these bodies contain sources of one or all of the three following types:

1. Electrically neutral aggregates of charged particles that possess no finite external electromagnetic field when undisturbed.

2. Aggregates possessing a finite external field, which may or may not be electrically neutral as to total charge.

3. Individual charges or charged particles moving independently of one another and of aggregates of particles.

Excitation of an electrical, mechanical, or thermal nature suffices to excite these three types of sources: type (1) to lined spectral radiation, types (2) and (3) to radiation of the black-body type.

To account for the broadening of spectral lines or the emission of continuous spectra, it is unnecessary to assume damping of the radiator.

Bodies possess in general, not only a fusion temperature and a temperature of vaporization, but an *ionization temperature* lying within the range of from 3,000° to 10,000° for elementary gases, and lower for other substances.

Purely thermal heating of a body to the neighborhood of its ionization temperature is sufficient to cause radiation.

It would be difficult, if not impossible, to heat a body by electrical or thermal means above its ionization temperature; hence there is an upper limit not exceeded by stellar temperatures.

BUREAU OF STANDARDS,
WASHINGTON, D. C.,
April 1905.

SPECTRA OF WEAK LUMINESCENCES. II

THE THERMO-LUMINESCENCE SPECTRUM OF FLUOR-SPAR

By HARRY W. MORSE

That many substances become luminescent on being heated to a temperature far below that of incandescence has been known for a very long time, and descriptions of these phenomena may be found in nearly all of the reports on "phosphorescence" which were frequent forty or fifty years ago.[1] Among thermo-luminescent substances two have been especial objects of interest: luminescent diamonds, which were known at least as far back as the time of Boyle, and the mineral fluor-spar. Some thermo-luminescent crystals were sent to the French Academy of Sciences in 1724, and from the description of the results of the examination made of them it would seem certain that they were crystals of fluor-spar.

The general appearance of the light emitted by these substances when they are heated has been frequently studied and described. Becquerel gives a quite complete résumé of the observations of French and English scientists on these phenomena,[2] and he made also a number of experiments on the relation of temperature and luminescence, and on the regeneration of the luminescence by light and by the electric spark, after the power to emit light had apparently been exhausted by continued heating. He also drew some conclusions with regard to the relation between the color of the crystals and their thermo-luminescence. Becquerel's account of the work of the German scientists is by no means so complete, and many interesting points connected with the phenomena in question are to be found in the researches of Osann, Fiebig,[3] and others. In the research of Fiebig an important question is brought up, namely, whether a substance must at some previous time have been exposed to light in order that it shall exhibit thermo-luminescence. The

[1] Among the older researches those of Wedgewood, *Phil. Trans.*, 1792, and Brewster, *Edin. Phil. Mag.*, **1**, 383, contain especially large lists of thermo-luminescent substances.

[2] *La Lumière*, **1**, 22, and 43. [3] *Pogg. Ann.*, **114**, 292, 1861.

evidence offered is not conclusive, but later researches have shown that a substance may exhibit strong thermo-luminescence without having been exposed to any light for at least many thousand years.

Data on the spectrum of the light emitted by thermo-luminescent substances is almost entirely lacking. Becquerel himself, who usually had no fear of weak luminescences, and who examined with apparatus giving considerable dispersion many spectra of phosphorescence, admits that he was unable to analyze the light from thermo-luminescent substances with any satisfactory results. I have found only one reference which suggests that the author really observed a spectrum of the same kind as those which I have photographed, and that is a brief note in *Poggendorff's Annalen* "from a letter from Herr Kindt."[1] The statement is here made that the spectrum from a certain crystal of fluor-spar is not continuous, but has strong dark bands in it "much like the absorption bands in the spectrum of the didymium salts."

The general facts concerning the production of a thermo-luminescence may be briefly summarized as follows:

1. Certain minerals (fluor-spar, diamond, leucophane, apatite, scheelite, etc.) and many artificially prepared sulphides of the alkaline-earth metals, as well as many salts, emit light when heated to a temperature below that of incandescence.

2. These substances appear without exception to exhibit fluorescence or phosphorescence, or both, under excitation by light, but many of the most brilliantly thermo-luminescent substances are not at all brilliant in fluorescence or phosphorescence, and many brilliantly fluorescent or phosphorescent substances exhibit no measurable thermo-luminescence.

3. There appears to be, for each substance, a quite definite relation between the time of heating, the temperature, and the intensity of the luminescence. Some phosphorescent sulphides may be exhausted of thermo-luminescence at a high temperature in a few seconds, while the luminescence of a crystal of fluor-spar may be either exhausted in a minute or so (at a red heat), or may persist for many hours at nearly constant intensity (at, say, 100° C.). Measurements of the relation between temperature, time of heating, and intensity of emitted light have not yet been made.

[1] *Ibid.*, **131**, 160.

4. The temperature at which light begins to be emitted by these substances may be a comparatively very low one. Some specimens of chlorophane and certain diamonds (especially Brazilian ones) are sensitive enough to show luminescence plainly when warmed by the hand, and many other substances show the effect brightly when heated to 200° C.

5. In many cases the entire store of light contained in the substance does not appear to become exhausted by heating to a temperature lower than a certain definite maximum, no matter how long the heating is continued. For, after all emission of light has ceased at a low temperature, more is produced by raising the temperature to a higher point, and when the light supply at this higher temperature has become exhausted, still more may be obtained by another increase in temperature. There appears, however, to be a certain maximum temperature at which all of the store of light in the substance is exhausted, and further increase of temperature beyond that point does not result in further luminescence.[1]

6. On standing in the dark the power to emit light on being heated is not regenerated. With respect to the regeneration of this power by light or by the action of the electric spark, various substances show differences so great as to make it certain that the phenomena are complex in their nature, and connected with more than one cause. The phosphorescent sulphides are easily regenerated by a short exposure to light, as would naturally be expected from the method of their preparation. But crystals of chlorophane (the name is applied to a variety of fluorite which exhibits a strong green thermo-luminescence) cannot be restored to their original condition by any amount of exposure to either light or the electric spark. They may be given the power to thermo-luminesce with another (usually purple or lavender) color in much less intensity, but they never recover the power of emitting the original bright green.

The present paper contains data on the spectra of thermo-luminescence of two distinct varieties of fluorite, one a "chlorophane" from Amelia Court House, Va., and the other a common, clear, color-

[1] See Le Bon, *Revue Scientifique*, **14**, 289 and 327. My own results agree with those of Le Bon so far as the facts connecting temperature and light-emission are concerned. With some of the conclusions drawn I should not agree.

less (or very slightly greenish) specimen from Westmoreland, N. H. Both are slightly fluorescent under the influence of ultra-violet light, the fluorescence color being the usual lavender common apparently to all fluorites under these conditions; and both are phosphorescent, exhibiting the lavender-colored light for some time after exposure to the spark. Neither is at all brilliantly fluorescent or phosphorescent under any circumstances in which I have so far placed them; but both are very strongly thermo-luminescent, the chlorophane emitting a very strong bright green light, perfectly visible in a well-lighted room, and the other fluorite emitting a lavender or purple light, not very different to the eye from the light emitted by the same substance in fluorescence and phosphorescence.

Results of more directly physical and chemical interest will be taken up more fully in another place. Of especial spectroscopic interest are the thermo-luminescence spectra of these two minerals and certain relations existing between them.

Examined visually (with a small direct-vision spectroscope) the light from either substance gives a discontinuous spectrum. The chlorophane yields a nearly continuous band with the maximum in the green-yellow, and, superimposed over this, a series of sharp lines. The light from the other fluorite consists of several broad bands of diffuse nature, with a sharp-line spectrum above them. The broad bands in the two spectra make up the greater part of the emitted light, and the lines are much obscured by their presence.

Close examination of the chlorophane shows that there are at least three distinct stages in the light-emission. At a low temperature (50°–100°) the green light appears. After this has begun to grow dim with increasing temperature, a yellowish color of less intensity and shorter duration takes its place, to be in turn replaced by a weak lavender luminescence at still higher temperature. This last color is much like that of the fluorescence under the influence of light. The luminescence during the two later stages of heating the chlorophane is so feeble and evanescent that photography of the spectrum of each stage separately seems to be a very difficult task. In the case of the colorless fluorite I have not been able to separate distinct stages differing markedly in color, but it is evident that the light produced at higher temperature, toward the end of the light-emission,

is of a deeper purple color than that emitted at lower temperatures.

As has been stated, the chlorophane begins to glow at a very low temperature. It reaches its maximum at a point not much above 350°. The other fluorite requires a higher temperature to start the luminescence, and the temperature must be increased to a slightly higher point to completely exhaust its power of emission.

Experimentally, the photography of spectra of luminescences of this intensity offers no difficulty whatever. Patience is necessary, since a large amount of material must be allowed to luminesce in front of the slit of the spectrograph, and the time during which a single crystal of fluorite glows brightly is rather short. Exposures of about four hours were required to yield clear, measurable plates, using the wide-range spectrograph described in a previous paper in this journal (**21**, 83, March, 1905). Longer ones could have been made, but the advantage gained is small, since the continuous diffuse portions increase so rapidly that the lines are not much more clearly differentiated than with the shorter exposure. Much advantage would be gained here by the use of greater dispersion, as the sharp lines could then be brought out while the continuous background remained weak. For this preliminary study, however, the spectrum as a whole is of interest, and the dispersion employed is well suited for the purpose.

After discarding mechanical arrangements of the nature of hot revolving plates and dishes, the simplest possible method of exposure was employed. The material was heated in a test-tube out of range of the slit until it began to glow. It was then held in front of the slit until the glow from the first heating began to grow weak, and it was then reheated, brought back in front of the slit, and so on until the luminescence was exhausted. Fresh material was then put through the same treatment, and the process continued through the time of exposure. Later a small electric furnace was used in the same way, the only advantage which it has over the test-tube being the better control of the temperature. This is in part offset by the difficulty of keeping the brightest luminescence directly in front of the slit when the furnace is used. The heated crystals decrepitate, and break up into smaller cleavage-pieces, and occasionally a heavy explosion within the crystal blows everything out of the furnace, or at least disturbs the position of the main mass of luminescent

material. The test-tube, held in the hand, can be turned so that the brightest place is toward the slit, and in general the cruder method is at least as easy in the end.

The presence of the strong diffuse underlying spectrum makes decision as to the sharpness of lines very difficult, and "intensity" values for lines in the diffuse bands are of course of little value. Intensities are, however, given in the tables on a scale of 1 to 10.

In all of the photographs taken magnesium was used as comparison metal, and lines of the luminescence spectrum which fall near sharp *Mg* lines can therefore be measured with considerable accuracy. It is on the basis of these lines that the values in the column headed "Maximum Error" are given. For example, the line at λ4347, a sharp, strong line of the thermo-luminescence in both varieties of the mineral, lies near the line λ4352 of the *Mg* spark spectrum, and the error of measurement on several plates is not greater than the value given. The line at λ5893 coincides exactly with the unresolved sodium lines in the comparison spectrum.

It would appear proven that the sharp-line portion of the spectrum

TABLE I

CHLOROPHANE FROM AMELIA COURT HOUSE, VA.

Continuous spectrum from violet to red, with maximum in the green-yellow both visually and in photographs. Superimposed over this continuous band the following lines have been measured:

4125	2	diffuse	
4145	2	diffuse	
4315	1	diffuse	blue group
4325	2	sharp	
4335	1	diffuse	
4347	10	sharp	
4365	4	diffuse	
4415	5	nearly sharp	
4457	2		
4525	1	diffuse	nearly hidden in continuous band
4580	5	sharp	
4630	1	diffuse	
4700	2	sharp	
5175		diffuse	green-yellow group (maxima in the continuous band)
5375	5	sharp	
5400		diffuse	
5435		diffuse	
5500		diffuse	
5600		diffuse	
5700		diffuse	
5893		double ?	

TABLE II

FLUOR-SPAR FROM WESTMORELAND, N. H.

4108	1	sharp	4622	1	diffuse
4130	2	diffuse	4658	4	sharp
4150	2	diffuse	4690	2	sharp
4192	1	diffuse	4703	2	sharp
4230	2	diffuse	4715	1	diffuse
4250	2	diffuse	4770	5	nearly sharp
4298	1	diffuse	4800	2	nearly sharp
4312	1	diffuse	4815	3	nearly sharp
4330	2	diffuse	4840	7	diffuse
4347	10	sharp	4892	6	nearly sharp
4365	5	maxima in diffuse band	4903	5	nearly sharp
4370	2		5200 to 5265		broad band
4382	2	sharp in diffuse band			
4398	1				
4415	5	not quite sharp	5375	9	sharp
4450	1	diffuse	5435	4	sharp
4462	2	diffuse	5520	2	sharp
4475	1	diffuse	5720	1	diffuse
4502	2	diffuse	5800	1	diffuse
4540	2	diffuse	5893	5	(sodium lines unresolved?)
4580	4	sharp			

TABLE III

LINES COMMON TO BOTH SPECTRA

Westmoreland	Chlorophane	Mean	Intensity	Maximum Error
4130	4125	4127	2	
4150	4145	4147	2	
4312	4315	4313	1	
4330	4325, 4335	4330	2	
4347	4347	4347	10	±2 tenth-meters
4365	4365	4365	5	±2 tenth-meters
4415	4415	4415	5	
4462	4457	4460	2	
4580	4580	4580	4	
4625	4630	4627	1	
4690, 4703	4700	4700	2	
5375	5375	5375	9	±3 tenth-meters
5435	5435	5435	4	±4 tenth-meters
5893	5893 (?)	5893	5	±2 tenth-meters

from the two fluorites is the same. All of the strong lines agree in wave-length and relative intensity within the limit of accuracy of the measurements. The diffuse bands of the two spectra are, however, entirely different, and the color of the thermo-luminescence light is due to the preponderance of this series of diffuse bands, the sharp-line portion being in each case comparatively weak.

All attempts to place these sharp lines to the credit of any known elements have been unsuccessful. There are, of course, many coincidences with lines of well-known substances, especially since the accuracy of measurement is so small, but other strong lines of the substance are absent, and one would demand the coincidence of an entire series of lines before admitting that a metal or gas could yield a line spectrum under the conditions of the experiment. The very exact coincidence of the line at λ 5893 with the mean of the two sodium lines suggests the possibility that this may be that pair, unresolved; but it seems to me that resolution into the two constituents would be the very least that could be demanded before deciding that the sodium pair does actually appear under these circumstances. I should therefore wish to reserve any decision on this point until the resolution has been accomplished.

There can be no doubt that these spectra are composites, and that the sources of luminescence, whatever their character, are capable of two distinct kinds of vibration. It seems not too much to conclude that one of these sources gives rise to the diffuse band spectrum, very similar to most spectra of fluorescence and phosphorescence, and entirely different in the two fluorites; while the other source is capable of giving a spectrum in all respects similar to the sharp-line spectra which are usually associated with incandescent gases, the latter source being *common to the two fluorites.*

A generous grant from the Rumford Fund of the American Academy of Arts and Sciences has been of much aid in this work, and a continuance of the investigation is already under way.

JEFFERSON PHYSICAL LABORATORY,
HARVARD UNIVERSITY,
May 1, 1905.

INDEX TO VOLUME XXI

SUBJECTS.

PAGE

ABBE, ERNST - - - - - - - - - - - - - - - 379
ABSORPTION Spectra, Dispersion Bands in. *W. H. Julius* - - - 271
AIR, Conditions Attending Appearance of Argon Lines in. *A. S. King* - 344
ALKALINE-Earth Fluorides in Electric Arc, On Spectra of. *Ch. Fabry* - - 356
ANOMALOUS Dispersion, Spectroheliographic Results Explained by. *W. H. Julius* - - - - - - - - - - - - - - - 278
ARC, On Spectra of Alkaline-Earth Fluorides in Electric. *Ch. Fabry* - - 356
Spectrum of Strontium, Additional Triplets in. *A. Fowler* - - 81
ARGON Lines in Air, Conditions Attending Appearance of. *A. S. King* - 344
ASTROPHYSICAL Journal, Grant by Smithsonian Institution to. - - - 81
ATMOSPHERE, "Optical Power" of, and its Measurement. *Karl Exner* and *W. Villiger* - - - - - - - - - - - - 368
Radiation Through a Foggy. *Arthur Schuster* - - - - - - 1
Temperature of the Solar. *Arthur Schuster* - - - - - - 258
ε Aurigae, Polaris, η Piscium, and *β Orionis*, On Radial Velocities of. *W. W. Campbell* and *Heber D. Curtis* - - - - - - - 191
BANDS in Absorption Spectra, Dispersion. *W. H. Julius* - - - 271
In the Spectra of *δ Orionis* and *Nova Persei*, Dispersion. *W. H. Julius* - - - - - - - - - - - - - - - 286
BOOKS Received - - - - - - - - - - - - - - 295
BRUCE Photographic Telescope of Yerkes Observatory. *E. E. Barnard* - 35
CALCIUM and Strontium, Narrow Triplets in Spectra of. *F. A. Saunders* - 195
CAPACITY and Self-induction upon Wave-Length in Spark Spectrum, Effect of. *George W. Middlekauff* - - - - - - - - - - 116
CARNEGIE Institution of Washington, Solar Observatory of. *George E. Hale* - - - - - - - - - - - - - - - 151
COMET 1903 IV, Motion of Matter Composing Tail of. *R. Jaegermann* - 323
CORONA, On Comparative Luminosity and Total Radiation of Solar. *S. P. Langley* - - - - - - - - - - - - - - 194
DISPERSION Bands in Absorption Spectra. *W. H. Julius* - - - 271
Bands in Spectra of *δ Orionis* and *Nova Persei*. *W. H. Julius* - - 286
Spectroheliographic Results Explained by Anomalous. *W. H. Julius* 278
ELECTRIC Oven, Some Emission Spectra of Metals as Given by. *A. S. King* 236
EMISSION Spectra of Metals as Given by an Electric Oven. *A. S. King* - 236
ENHANCED Lines of Iron, Titanium and Nickel. *F. E. Baxandall* - - 337
FLUORIDES in Electric Arc, On Spectra of Alkaline-Earth. *Ch. Fabry* - 356
FOGGY Atmosphere, Radiation Through. *Arthur Schuster* - - - 1

PAGE

GLASS and Silvered Glass Mirrors, Some New Determinations of Reflecting Powers. *C. A. Chant* - - - - - - - - - - - 211
GRATING Spectra, Intensity of. *R. W. Wood* - - - - - - - 173
HIGH-Temperature Radiation. *P. G. Nutting* - - - - - - 400
INTERRUPTER, Spectra from Wehnelt. II. *Harry W. Morse* - - 223
IRON, Titanium and Nickel, On Enhanced Lines of. *F. E. Baxandall* - 337
LUMINESCENCES, Spectra of Weak. *Harry W. Morse* - - - - 83, 410
MAGNESIUM, On Spectrum of. *James Barnes* - - - - - - - 74
MAGNETIC Disturbances, Solar Origin of Terrestrial. *E. Walter Maunder* 101
MATTER Composing Tail of Comet 1903 IV, Motion of. *R. Jaegermann* - 323
McMILLIN Observatory, Observations of Radial Velocities of Thirty-one Stars Made at the Emerson. *H. C. Lord* - - - - - - 297
METALS as Given by an Electric Oven, Some Emission Spectra of. *A. S. King* - - - - - - - - - - - - - - - 236
MIRRORS, Some New Determinations of Reflecting Powers of Glass and Silvered Glass. *C. A. Chant* - - - - - - - - - 211
MONOCHROMATIC Photographs of the *Orion* Nebula. *J. Hartmann* - 389
MOON'S Spectrographic Velocity near Full Moon, Computation of. *R. H. Curtiss* - - - - - - - - - - - - - - 376
MOTION of Matter Composing Tail of Comet 1903 IV. *R. Jaegermann* - 323
MT. WILSON, California, Study of Conditions for Solar Research at. *George E. Hale* - - - - - - - - - - - - - - 124
NICKEL, On Enhanced Lines of Iron, Titanium and. *F. E. Baxandall* - 337
Nova Persei, Dispersion Bands in Spectra of δ *Orionis* and. *W. H. Julius* - 286
OBSERVATORY of Carnegie Institution of Washington, Solar. *George E. Hale* - - - - - - - - - - - - - - - 151
"OPTICAL Power" of the Atmosphere and its Measurement. *Karl Exner* and *W. Villiger* - - - - - - - - - - - - - 368
OPTICS of the Spectroscope. *Arthur Schuster* - - - - - - 197
δ *Orionis* and *Nova Persei*, Dispersion Bands in Spectra of. *W. H. Julius* 286
β *Orionis*, *Polaris*, η *Piscium*, and ε *Aurigæ*, On Radial Velocities of. *W. W. Campbell* and *Heber D. Curtis* - - - - - - - 191
Orion Nebula, Monochromatic Photographs of. *J. Hartmann* - - 389
OVEN, Some Emission Spectra of Metals as Given by an Electric. *A. S. King.* - - - - - - - - - - - - - - - 236
Persei, Dispersion Bands in the Spectra of δ *Orionis* and *Nova*. *W. H. Julius* - - - - - - - - - - - - - - - 286
PHOTOGRAPHS of the *Orion* Nebula, Monochromatic. *J. Hartmann* - 389
η *Piscium*, ε *Aurigae*, β *Orionis*, and *Polaris*, On Radial Velocities of. *W. W. Campbell* and *Heber D. Curtis* - - - - - - - - - 191
Polaris, η *Piscium*, ε *Aurigae*, and β *Orionis*, On Radial Velocities of. *W. W. Campbell* and *Heber D. Curtis* - - - - - - - 191
POTSDAM Observatory, Spectroheliograph of. *P. Kempf* - - - - 49

PAGE
POULKOVA, Determination of Radial Velocities at. *A. Bélopolsky* - - 55
POWERS of Glass and Silvered Glass Mirrors, Some New Determinations of Reflecting. *C. A. Chant* - - - - - - - - - - - 211
RADIAL Velocities of Thirty-one Stars Made at Emerson McMillin Observatory, Observations of. *H. C. Lord* - - - - - - - 297
Velocities at Poulkova, On Determination of. *A. Bélopolsky* - - 55
Velocities of *Polaris*, *η Piscium*, *ε Aurigae*, and *β Orionis*. *W. W. Campbell* and *Heber D. Curtis* - - - - - - - - - 191
Velocities Vary, List of Nine Stars Whose. *W. W. Campbell* and *Heber D. Curtis* - - - - - - - - - - - - 185
Velocities Vary, List of Twelve Stars Whose. *W. H. Wright* - 371
Velocity of *Sirius*, Variable. *W. W. Campbell* - - - - - - 176
RADIATION, High-Temperature. *P. G. Nutting* - - - - - - 400
Through a Foggy Atmosphere. *Arthur Schuster* - - - - - 1
REFLECTING Powers of Glass and Silvered Glass Mirrors, Some New Determinations of. *C. A. Chant* - - - - - - - - - - 211
REVIEWS, See Table of Contents
REVISION of Rowland's System of Standard Wave-lengths. *Lewis E. Jewell* - - - - - - - - - - - - - - - 23
ROWLAND'S System of Standard Wave-lengths, Revision of. *Lewis E. Jewell* - - - - - - - - - - - - - - - - 23
RUMFORD Spectroheliograph, Observations with. *Philip Fox* - - - 351
Spectroheliograph, The Work of. *George E. Hale* - - - - - 261
SELF-induction Upon Wave-Length in Spark Spectrum, Effect of Capacity and. *George W. Middlekauff* - - - - - - - - - 116
SMITHSONIAN Institution, Grant to *Astrophysical Journal* - - - 81
Sirius, The Variable Velocity of. *W. W. Campbell* - - - - - 176
SOLAR Atmosphere, Temperature of. *Arthur Schuster* - - - - - 258
Observatory of Carnegie Institution of Washington. *George E. Hale* 151
Origin of Terrestrial Magnetic Disturbances. *E. Walter Maunder* - 101
Research at Mt. Wilson, California. Study of Conditions for. *George E. Hale* - - - - - - - - - - - - - - - 124
SPARK Spectrum, Effect of Capacity and Self-induction Upon Wave-Length in. *George W. Middlekauff* - - - - - - - - - - 116
SPECTRA, Dispersion Bands in Absorption. *W. H. Julius* - - - 271
From Wehnelt Interrupter. II. *Harry W. Morse* - - - - 223
Of Alkaline-Earth Fluorides in Electric Arc. *Ch. Fabry* - - - 356
Of Calcium and Strontium, Narrow Triplets in. *F. A. Saunders* - 195
Intensity of Grating. *R. W. Wood* - - - - - - - - - 173
Of Metals as Given by an Electric Oven, Some Emission. *A. S. King* 23
Of *δ Orionis* and *Nova Persei*, Dispersion Bands in. *W. H. Julius* - 286
Of Weak Luminescences. *Harry W. Morse* - - - - - 83, 410
Stars Having Peculiar. *Edward C. Pickering* - - - - - - 292

PAGE

SPECTROGRAPHIC Velocity Near Full Moon, Computation of Moon's. *R. H. Curtiss* - - - - - - - - - - - - - 376
SPECTROHELIOGRAPHIC Results Explained by Anomalous Dispersion. *W. H. Julius* - - - - - - - - - - - - 278
SPECTROHELIOGRAPH Observations With Rumford. *Philip Fox* - - 351
Of Potsdam Observatory. *P. Kempf* - - - - - - - 49
Work of the Rumford. *George E. Hale* - - - - - - - 261
SPECTROSCOPE, The Optics of. *Arthur Schuster* - - - - - 197
SPECTRUM, Effect of Capacity and Self-induction Upon Wave-Length in Spark. *George W. Middlekauff* - - - - - - - - 116
Of Argon, Appearance of, in Air. *A. S. King* - - - - - 344
Of Magnesium. *James Barnes* - - - - - - - - - 74
Of Strontium, Additional Triplets in Arc. *A. Fowler* - - - 81
STANDARD Wave-Length, Revision of Rowland's System of. *Lewis E. Jewell* - - - - - - - - - - - - - - 23
STARS Having Peculiar Spectra. *Edward C. Pickering* - - - - 292
Whose Radial Velocities Vary, List of Nine. *W. W. Campbell* and *Heber D. Curtis* - - - - - - - - - - - - 185
STRONTIUM, Additional Triplets in Arc Spectrum of. *A. Fowler* - - 81
Narrow Triplets in Spectra of Calcium and. *F. A. Saunders* - - 195
TACCHINI, PIETRO - - - - - - - - - - - - - - 387
TELESCOPE, Bruce Photographic, of Yerkes Observatory. *E. E. Barnard* 35
TEMPERATURE of the Solar Atmosphere. *Arthur Schuster* - - - 258
TERRESTRIAL Magnetic Disturbances, Solar Origin of. *E. Walter Maunder* 101
TITANIUM, Iron and Nickel, On Enhanced Lines of. *F. E. Baxandall* - 337
TRIPLETS in Arc Spectrum of Strontium, Additional. *A. Fowler* - - 81
In Spectra of Calcium and Strontium, Note on Narrow. *F. A. Saunders* 195
VELOCITIES of *Polaris*, *η Piscium*, *ε Aurigæ*, and *β Orionis*, On the Radial. *W. W. Campbell* and *Heber D. Curtis* - - - - - - - 191
Of Thirty-one Stars Made at the Emerson McMillin Observatory, Observations of Radial. *H. C. Lord* - - - - - - - 297
On Determination of Radial, at Poulkova. *A. Bélopolsky* - - 55
Vary, List of Nine Stars Whose Radial. *W. W. Campbell* and *Heber D. Curtis* - - - - - - - - - - - - - 185
Vary, List of Twelve Stars Whose Radial. *W. H. Wright* - - 371
VELOCITY of *Sirius*, The Variable Radial. *W. W. Campbell* - - - 176
Near Full Moon, Computation of the Moon's Spectrographic. *R. H. Curtiss* - - - - - - - - - - - - - - 376
WAVE-LENGTH in Spark Spectrum, Effect of Capacity and Self-induction Upon. *George W. Middlekauff* - - - - - - - - - 116
WAVE-LENGTHS, Revision of Rowland's System of Standard. *Lewis E. Jewell* - - - - - - - - - - - - - - 23
WEHNELT Interrupter, Spectra from. II. *Harry W. Morse* - - - 223
YERKES Observatory, Bruce Photographic Telescope of. *E. E. Barnard* 35

INDEX TO VOLUME XXI

AUTHORS

PAGE

ADAMS, WALTER S. Review of: *Spectroscopic Observations of the Rotation of the Sun*, J. Halm - - - - - - - - - - 385

BARNARD, E. E. The Bruce Photographic Telescope of the Yerkes Observatory - - - - - - - - - - - - - - - 35

BARNES, JAMES. On the Spectrum of Magnesium - - - - - 74

BAXANDALL, F. E. On the Enhanced Lines of Iron, Titanium and Nickel 337

BÉLOPOLSKY, A. On the Determination of Radial Velocities at Poulkova - 55

CAMPBELL, W. W. The Variable Radial Velocity of *Sirius* - - - 176

CAMPBELL, W. W., and HEBER D. CURTIS. A List of Nine Stars whose Radial Velocities Vary - - - - - - - - - - - - 185

CAMPBELL, W. W., and HEBER D. CURTIS. On the Radial Velocities of *Polaris*, *η Piscium*, *ε Aurigae*, *β Orionis* - - - - - - - 191

CHANT, C. A. Some New Determinations of the Reflecting Powers of Glass and Silvered Glass Mirrors - - - - - - - - 211

CURTIS, HEBER D., and W. W. CAMPBELL. A List of Nine Stars Whose Variable Velocities Vary - - - - - - - - - - - 185

On the Radial Velocities of *Polaris*, *η Piscium*, *ε Aurigae*, and *δ Orionis* - - - - - - - - - - - - - - - 191

CURTISS, R. H. On the Computation of the Moon's Spectrographic Velocity Near Full Moon - - - - - - - - - - - - - - 376

EXNER, KARL, and W. VILLIGER. The "Optical Power" of the Atmosphere and Its Measurement - - - - - - - - - - 368

FABRY, CH. On the Spectra of the Alkaline-Earth Fluorides in the Electric Arc - - - - - - - - - - - - - - - - 356

FOWLER, A. Note on Additional Triplets in the Arc-Spectrum of Strontium - - - - - - - - - - - - - - - - - 81

FOX, PHILIP. Observations With the Rumford Spectroheliograph - - 351

HALE, GEORGE E. A Study of the Conditions for Solar Research at Mt. Wilson, California - - - - - - - - - - - - 124

The Solar Observatory of the Carnegie Institution of Washington - 151

The Work of the Rumford Spectroheliograph - - - - - - 261

HARTMANN, J. Monochromatic Photographs of the *Orion* Nebula - - 389

JAEGERMANN, R. The Motion of the Matter Composing the Tail of Comet 1903 IV, observed July 24, 1903 - - - - - - - - 323

JEWELL, LEWIS E. The Revision of Rowland's System of Standard Wave-Lengths - - - - - - - - - - - - - - - - 23

PAGE

JULIUS, W. H. Dispersion Bands in Absorption Spectra - - - 271
Dispersion Bands in the Spectra of δ *Orionis* and *Nova Persei* - 286
Spectroheliographic Results Explained by Anomalous Dispersion - 278
KEMPF, P. The Spectroheliograph of the Potsdam Observatory - - 49
KING, A. S. Note on the Conditions Attending the Appearance of the Argon Lines in Air - - - - - - - - - - - 344
Some Emission Spectra of Metals as Given by an Electric Oven - 236
LANGLEY, S. P. On the Comparative Luminosity and Total Radiation of the Solar Corona - - - - - - - - - - - 194
LORD, H. C. Observations of the Radial Velocities of Thirty-one Stars Made at the Emerson McMillin Observatory - - - - - 297
MAUNDER, E. WALTER. The Solar Origin of Terrestrial Magnetic Disturbances - - - - - - - - - - - - - 101
MIDDLEKAUFF, GEORGE W. The Effect of Capacity and Self-Induction Upon Wave-Length in the Spark Spectrum - - - - - - 116
MORSE, HARRY W. Spectra of Weak Luminescences - - - - 83, 410
Spectra from the Wehnelt Interrupter. II - - - - - - 223
NICHOLS, E. F. Review of: *An Introduction to the Theory of Optics.* Arthur Schuster - - - - - - - - - - - 382
NUTTING, P. G. High-Temperature Radiation - - - - - - 400
PICKERING, EDWARD C. Stars Having Peculiar Spectra - - - - 292
SAUNDERS, F. A. Note on Narrow Triplets in the Spectra of Calcium and Strontium - - - - - - - - - - - - - 195
SCHUSTER, ARTHUR. Radiation Through a Foggy Atmosphere - - 1
The Optics of the Spectroscope - - - - - - - - - 197
The Temperature of the Solar Atmosphere - - - - - - 258
VILLIGER, W., and KARL EXNER. The "Optical Power" of the Atmosphere and Its Measurement - - - - - - - - - 368
WOOD, R. W. Intensity of Grating Spectra - - - - - - - 173
WRIGHT, W. H. A List of Twelve Stars Whose Radial Velocities Vary - 371
YOUNG, C. A. Review of: *Astronomical Discovery*, Herbert Hall Turner - - - - - - - - - - - - - 383

1698
GENERAL LIBRARY,
UNIV. OF MICH.
JUN 10 1905

THE ASTROPHYSICAL JOURNAL

An International Review of Spectroscopy and Astronomical Physics

EDITED BY

GEORGE E. HALE
Solar Observatory of the Carnegie Institution

EDWIN B. FROST
Yerkes Observatory of the University of Chicago

WITH THE COLLABORATION OF

J. S. AMES, Johns Hopkins University
A. BÉLOPOLSKY, Observatoire de Poulkova
W. W. CAMPBELL, Lick Observatory
HENRY CREW, Northwestern University
N. C. DUNÉR, Astronomiska Observatorium, Upsala
C. S. HASTINGS, Yale University
WILLIAM HUGGINS, Tulse Hill Observatory, London
H. KAYSER, Universität Bonn
A. A. MICHELSON, University of Chicago
ERNEST F. NICHOLS, Columbia University
E. C. PICKERING, Harvard College Observatory
C. RUNGE, Technische Hochschule, Hannover
P. TACCHINI, Osservatorio del Collegio Romano, Rome
H. C. VOGEL, Astrophysikalisches Observatorium, Potsdam
F. L. O. WADSWORTH, Morgantown, W. Va.
C. A. YOUNG, Princeton University

JUNE 1905

CONTENTS

MONOCHROMATIC PHOTOGRAPHS OF THE *ORION* NEBULA - - J. HARTMANN 389
HIGH-TEMPERATURE RADIATION - - - - - - - - - P. G. NUTTING 400
SPECTRA OF WEAK LUMINESCENCES, II. THE THERMO-LUMINESCENCE SPECTRUM OF FLUOR-SPAR - - - - - - - - - HARRY W. MORSE 410

The University of Chicago Press
CHICAGO AND NEW YORK
WILLIAM WESLEY & SON, London

READY FOR CONQUEST

There's a wealth of health and beauty
that is irresistible
in the matchless complexion derived
from the use of

PEARS' SOAP

Of all Scented Soaps Pears' Otto of Rose is the best.

All rights secured

She say's

"Be sure and get a

Waterman's Ideal Fountain Pen

before you start

It's the one indispensable vacation companion"

The Clip-Cap is a protection against loss. Grips the pocket but is easily detached.

Educators Beware

of spurious and fraudulent imitations of the Waterman Pens.

For Sale by Dealers.

L.E. Waterman Co.

173 Broadway, New York
138 Montgomery St., San Francisco.
160 State St., Chicago.
8 School St., Boston.
12 Golden Lane, London.
136 St. James St., Montreal.
6 Rue de Hanovre, Paris.

Waiting for repairs

A Nutritious Food-Drink for all Ages

Shakespeare's Seven Ages

"It's meat and drink to me."

HORLICK'S MALTED MILK

1ST "THE INFANT IN THE NURSE'S ARMS"

4TH "THEN THE SOLDIER SEEKING REPUTATION AT THE CANNON'S MOUTH"

For the Seven Ages

is a delicious food-drink, unequaled for its nutritive and digestive properties. It builds up the infant, sustains the adult, invigorates the invalid, and nourishes the aged. More nutritious than milk for infants; more wholesome than tea or coffee for adults.

Pure, rich milk with the extract of selected malted grains. Ready in a moment by simply stirring in water. A glassful taken hot upon retiring brings refreshing sleep.

In Lunch Tablet form, also, with chocolate. A delightful confection for growing children. At all druggists. Sample mailed free upon request.

Our booklet with valuable recipes is also sent free if mentioned.

Ask for HORLICK'S; others are imitations.

Horlick's Food Company,
Racine, Wis., U. S. A.

London, England. *Montreal Canada.*

2ND "THEN THE SCHOOLBOY WITH HIS SHINING MORNING FACE"

5TH "AND THEN THE JUSTICE FULL OF WISE SAWS"

3RD "AND THEN THE LOVER WITH HIS BALLAD"

7TH "LAST SCENE THAT ENDS THIS EVENTFUL HISTORY"

6TH "WITH SPECTACLES ON NOSE"

THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

PUBLISHED MONTHLY EXCEPT IN FEBRUARY AND AUGUST

VOL. XXI JUNE 1905 NO. 5

MONOCHROMATIC PHOTOGRAPHS OF *ORION* NEBULA - J. HARTMANN 389

HIGH-TEMPERATURE RADIATION - - - - - - P. G. NUTTING 400

SPECTRA OF WEAK LUMINESCENCES. II. THE THERMO-LUMINESCENCE SPECTRUM OF FLUOR-SPAR - - - - HARRY W. MORSE 410

Editorial communications should be addressed to the Editors of The Astrophysical Journal, Yerkes Observatory, Williams Bay, Wis.

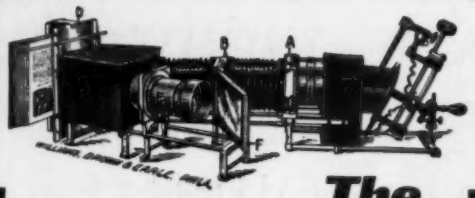
Business correspondence should be addressed to The University of Chicago Press, Chicago, Ill.

Subscription, $4.00 per year. Single copies 50 cents. Postage prepaid by publishers for all subscriptions in the United States, Canada, Mexico, Cuba, Porto Rico, Panama Canal Zone, Republic of Panama, Hawaiian Islands, Philippine Islands, Guam, Tutuila (Samoa), Shanghai. For all other countries in the Postal Union 75 cents for postage should be added to the subscription price.

Claims for missing numbers should be filed on or before thirty days after the date of publication.

European subscriptions, £1 per year (postage included), should be remitted to William Wesley & Son, 28 Essex Street, Strand, London, European agent.

Entered January 17, 1895, at the Post-Office at Chicago, Ill., as second-class matter, under Act of Congress March 3, 1879.
Copyright 1904 by The University of Chicago



The New Reflecting Lantern

For brilliantly projecting on the screen in natural colors photos, engravings, sketches, colored prints, flowers, specimens, mechanical models and cuts in books. Also shows lantern slides perfectly. Attachable to any electric lantern.

We also carry a large stock of Lantern Slides to illustrate Educational and Scientific Subjects.

Lantern Slides on Geography.
Lantern Slides on Geology and Botany.
Lantern Slides on Natural History.
Lantern Slides on Astronomy and Anatomy.
Lantern Slides on American History.
Lantern Slides on Psychology.
Lantern Slides on Engineering and Architecture.
Lantern Slides on Mining.
Lantern Slides illustrating many other subjects.

We rent slides at low rates. Send for lists, naming particular subject of interest.

WILLIAMS, BROWN & EARLE,
Manufacturers of Stereopticons, Microscopes, etc.,
Dept. 25 918 Chestnut St., Phila.

THE WESTON STANDARD
Voltmeters
—AND—
Ammeters

Portable
Accurate
Reliable and
Sensitive

WESTON ELECTRICAL INSTRUMENT CO.
Waverly Park, NEWARK, N. J.
Berlin—European Weston Electrical Instrument Co., Ritterstrasse No.88
London—Elliott Bros., Century Works, Lewisham.
Paris—France: C. H. Cadiot, 12 Rue St. Georges.
NEW YORK OFFICE—74 Cortlandt St.

Lectures on the Calculus of Variations

By OSKAR BOLZA, Ph.D.
Of the Department of Mathematics in the University of Chicago

$4.00, net; $4.16, postpaid

The University of Chicago Press
CHICAGO and 156 Fifth Avenue NEW YORK

The Physical Review

A JOURNAL OF EXPERIMENTAL AND THEORETICAL PHYSICS

Conducted with the co-operation of the

AMERICAN PHYSICAL SOCIETY

BY

EDWARD L. NICHOLS, ERNEST MERRITT and FREDERICK BEDELL

Published Monthly *Annual Subscription, Five Dollars*

Sample copy upon request

THE MACMILLAN COMPANY
66 Fifth Avenue, NEW YORK

The New Knowledge

A Popular Account of the New Physics and the New Chemistry in their Relation to the New Theory of Matter

By ROBERT KENNEDY DUNCAN

Professor of Chemistry in Washington and Jefferson College.
With many Illustrations. 8vo, cloth, **$2.00** net.

There is a New Knowledge in the world.

The Cause of the Heat of the Sun — **Radio-Activity**
The Immortality of the Universe — **The Birth and Decay of Matter**
A Tangible Conception of Eternity

All these are locked up in the New Knowledge that is revolutionizing the thought of the day.

The Right Life and How to Live It

By the Rev. Dr. HENRY A. STIMSON

"Only a boy with a very blunt nature can lay this book down without seeing that science as well as religion preaches upright conduct and clean living."—*New York Globe.*

Introduction by WILLIAM H. MAXWELL, Superintendent of Schools, New York City.

Price, **$1.20** net.

Our First Century A Little History of American Life

By GEORGE CAREY EGGLESTON

Here a century really lives.
Familiar facts are the landmarks—but the pictures are of the manners, customs, the daily activities of a people.

Numerous Illustrations, **$1.20** net.

NEW FICTION

Partners of the Tide
By JOSEPH C. LINCOLN
Author of "Captain Eri."
$1.50

Serena
By VIRGINIA FRAZER BOYLE
$1.50

The Wanderers
By HENRY C. ROWLAND
Author of "To Windward."
$1.50

On Tybee Knoll
By JAMES B. CONNOLLY
Author of "The Seiners."
$1.25

The White Terror and the Red
The Tragic History of Russia
By A. CAHAN
$1.50

The Sunset Trail
By ALFRED HENRY LEWIS
Author of "The President," "The Boss," Wolfville Days," etc.
$1.50

The Unwritten Law
By ARTHUR HENRY
Author of "The House in the Woods" and "An Island Cabin."
$1.50

SEND FOR OUR NEW CATALOGUE

156 Fifth Avenue **A. S. BARNES & CO., Publishers** New York City

Astronomical Photographs and Lantern Slides

To meet the demand for lantern slides and prints from astronomical photographs made at the Yerkes Observatory, arrangements have been made by which the University of Chicago Press can supply slides, transparencies, and prints to the general public. The stock is now in such shape that nearly all orders can be filled on short notice. Among the subjects available at the present time are:

THE SUN. Prominences, spots, and flocculi photographed with the new Rumford spectroheliograph attached to the 40-inch telescope, solar spectra, the corona, and similar solar phenomena.

THE MOON. Moon's disk at various phases, lunar mountains, and craters, and many enlarged details, taken with the 40-inch and 12-inch telescopes.

NEBULAE. The great nebulæ in *Andromeda* and *Orion*, dumb-bell nebula, *Nova Persei*, and others, taken with the two-foot reflector.

COMETS AND METEORS. Borrelly's comet, showing progressive changes in the tail, etc.

SPECTRA OF STARS. Numerous plates taken with the Bruce spectrograph, showing displacement due to velocity in line of sight, and to the Earth's motion, spectroscopic binaries, spectra of the *Orion* type; comparative spectra of the stars of the fourth type, of *Novæ*, and many others.

VARIABLE STAR FIELDS. A selection of about fifty fields, taken with the two-foot reflector.

STEREOSCOPIC PRINTS. Borrelly's comet, lunar phases, instruments, and buildings.

INSTRUMENTS. In addition to numerous miscellaneous slides of interest to astronomers, there is a full assortment of the instruments and buildings at the Yerkes Observatory.

PRINTS. Prints of various sizes can be supplied from nearly all the negatives.

A detailed catalogue of 12 pages will be sent upon application

The University of Chicago Press

Chicago, Illinois

THE PERRY PICTURES

For Picture Study and for teaching Language, Literature, History, Geography, etc.

ONE CENT EACH

for 25 or more. Assorted as desired. Size 5½ x 8. 2,000 subjects. 120 for $1.00. Larger size, 23 for $1.00.

Art subjects, poets, historical, geographical, etc.

Send two-cent stamp for catalogue, or three two-cent stamps for catalogue of 1,000 miniature illustrations, two pictures and a picture in three colors.

THE ONE CENT PICTURES ARE FIVE TO SEVEN TIMES THIS SIZE

Beautiful Pictures in Colors for *Bird Study* in *June*.

BIRDS PORTRAYED IN NATURAL COLORS **TWO CENTS EACH** for 13 or more. Assorted as desired. 648 subjects. 7 x 9. Send to day. *A cent and three-quarters each* in lots of 100 or more. ¶ Send 50 cents for Set A, 25 Common Birds, or Set B, 25 other Common Birds, or Set C, 25 Bird Homes. A little about each bird, written by Arthur C. Boyden, and copyrighted, will be sent free with each of these sets.

THE PERRY MAGAZINE, Monthly except July and August. $1.00 per year. Can you afford not to know about the World's Great Paintings? This magazine describes them. It teaches how to use pictures in school.

LARGE PICTURES FOR SCHOOL ROOM DECORATION, 22 x 28, 75 cents each. 8 for $5.00.

Gold Medal St. Louis Exposition, 1904.

THE PERRY PICTURES COMPANY
Box 501, MALDEN, MASS.

WANTED BACK NUMBERS OF THE ASTROPHYSICAL JOURNAL

Volume I, Nos. 1, 2, 3, 4 and 5 (January, February, March, April and May, 1905)
Volume VI, No. 3 (October, 1897)
Volume XIV, No. 4 (November, 1901)
Volume XV, No. 2 (February, 1902)
Volume XVI, No. 3 (October. 1902)
Volume XVII, Nos. 1 & 2 (January, February, 1903)
Volume XIX, No. 4 (May, 1904)

A liberal offer will be made for the foregoing issues

The University of Chicago Press *Chicago and 156 Fifth Ave., New York*

Light Waves and Their Uses

By Albert A. Michelson

1. **Wave Motion and Interference.**
2. **Comparison of the Efficiency of the Microscope, Telescope, and Interferometer.**
3. **Application of Interference Methods to Measurements of Distances and Angles.**
4. **Application of Interference Methods to Spectroscopy.**
5. **Light Waves as Standards of Length.**
6. **Analysis of the Action of Magnetism on Light Waves by the Interferometer and the Echelon.**
7. **Application of Interference Methods to Astronomy.**
8. **The Ether.**

With 108 text figures and three full-page lithographs.

Numerous practical applications of recent theories in optics together with accurate illustrations and descriptions of apparatus add materially to the value of this book. Students of physics and astronomy will find here an admirable condensation of the somewhat scattered literature of the subject, presented in an original and entertaining manner.

Price $2.00 net; $2.12 postpaid,

The University of Chicago Press

Chicago, and 156 Fifth Avenue, New York

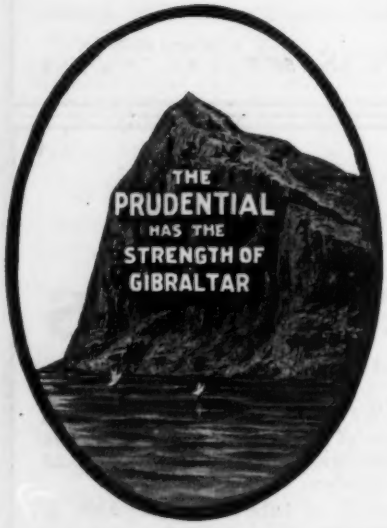
Practical Life Insurance

Combining { SAVING / INVESTMENT / PROTECTION } is Found in the

FIVE YEAR DIVIDEND POLICY

Issued by

The Prudential



The Premium is Low.

No Restriction as to Residence, Travel or Occupation.

Policy is Non-forfeitable after the first year, that is, if Premium is not paid the Policy is kept in force for a time specified in the Contract.

Liberal Loans are made on the Policy after three years (two years on Endowments).

Liberal Non-forfeitable Provisions:

Automatically Extended Insurance,
Paid-Up Insurance,
Cash Surrender Values,
All guaranteed in the Policy.

Policy provides for a *Life Income* to Beneficiary (if an Endowment, to the Insured while living and Beneficiary afterwards).

Cash Dividends are apportioned at the end of each Five Year Period and may be taken in Cash, used to reduce Premium, or to increase Insurance.

The PRUDENTIAL

Insurance Company of America

Incorporated as a Stock Company by the State of New Jersey

Home Office, Newark, N.J. JOHN F. DRYDEN, Pres.

Send in this Coupon

Without committing myself to any action, I shall be glad to receive free, specimen of Five Year Dividend Whole Life Policy.

For $.....

Name.....Age.....

Address.....

Occupation..... Dept. 25

If a Specimen Endowment or Limited Payment Policy is desired, specify instead of "Whole Life."

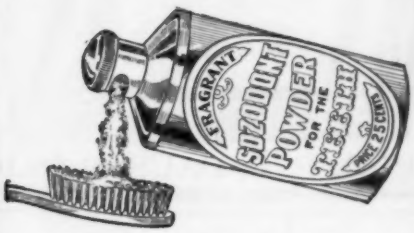
Brain Energy!

HORSFORD'S
ACID PHOSPHATE

A boon to business and Professional Men restoring the worn and tired brain to its normal condition.

RUMFORD CHEMICAL WORKS PROVIDENCE R.I.

Sozodont
Tooth Powder



a delicious dentifrice. Free from acid and grit. Just the thing for those who have an inclination for the niceties of every-day life.

FOR SALE EVERYWHERE

The Preserver and Beautifier of the Complexion.

A Positive Relief for Prickly Heat, Chafing and Sunburn.

MENNEN'S face on every box; be sure that you get the original. Sold everywhere, or by mail 25 cents. **Sample free.**

Gerhard Mennen Co., Newark, N. J.

TRY MENNEN'S VIOLET TALCUM.

"GEM" SAFETY RAZOR

SHAVE WITH A "GEM"
ON BOAT, TRAIN, ANYWHERE —

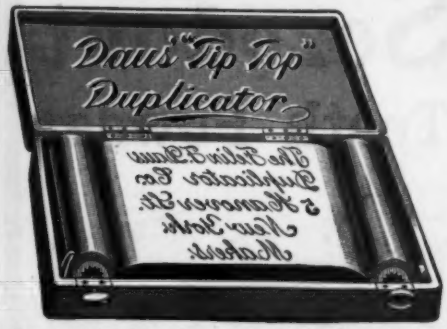
It's the easiest, quickest, simplest way, and a clean, close, comfortable shave is always assured—the "Gem" is perfect in every detail. Send for our *free* proposition, How to make and save money with a "Gem."

The "GEM" Blade is the secret of our success.

GEM RAZOR COMPLETE, $2.00

Sold everywhere or sent direct, all charges paid.

GEM CUTLERY CO. (Dept. 24), 34 Reade St., New York



What Is Daus' Tip-Top?

TO PROVE that Daus' "Tip-Top" Duplicator is the best, simplest, and cheapest device for making

100 copies from Pen-written and 50 copies from Typewritten original

we are willing to send a complete DUPLICATOR **without deposit on ten days' trial.**

No mechanism to get out of order, no washing, no press, no printer's ink. The product of 23 years' experience in DUPLICATORS. Price for complete apparatus, cap size (prints 8¼ in. by 13 in.), $7.50, subject to the trade discount of 33⅓ per cent. **$5.00 net.**

FELIX P. B. DAUS DUPLICATOR CO., Daus Bldg., 111 John Street, New York

The 20th Century Piano

Any piece of music sounds better on a

STROHBER PIANO

Price and Terms are better too

Direct from the Manufacturers

STROHBER PIANO CO., Chicago

The Land of Manatee

described and illustrated, its wonderful resources shown, and its strange and absorbingly interesting history recounted, in the Seaboard Magazine.

SENT FREE ON REQUEST

J. W. WHITE, General Industrial Agent
PORTSMOUTH, VIRGINIA

Seaboard Air Line Railway

THE UNIVERSITY OF CHICAGO PRESS

Educational and Scientific works *printed* in English, German, French, and all other modern languages. *Estimates furnished.*

58TH STREET AND ELLIS AVENUE, CHICAGO, ILLINOIS

We want and recommend **Athletic Coaches,** Physical Directors, and Teachers to combine athletic work with other branches, for high-grade positions. Have filled vacancies in University of Wisconsin, Purdue, Pratt Institute, high schools, etc., and can assist you. REGISTER NOW, FREE.

The Physical Training Teachers' Bureau, 212 South Second Street, ROCKFORD, ILL.

GRAND PRIZE
(the highest honor)

AWARDED TO

ESTERBROOK'S
Steel Pens

AT THE

St. Louis Exposition

THE IMPROVED
Boston
Garter

KNOWN AND WORN ALL OVER THE WORLD

The NAME is Stamped ON EVERY LOOP—

The Velvet Grip CUSHION BUTTON CLASP

Lies flat to the leg—never slips, tears, nor unfastens

EVERY PAIR WARRANTED

Send 50c. for Silk, 25c. for Cotton, Sample Pair

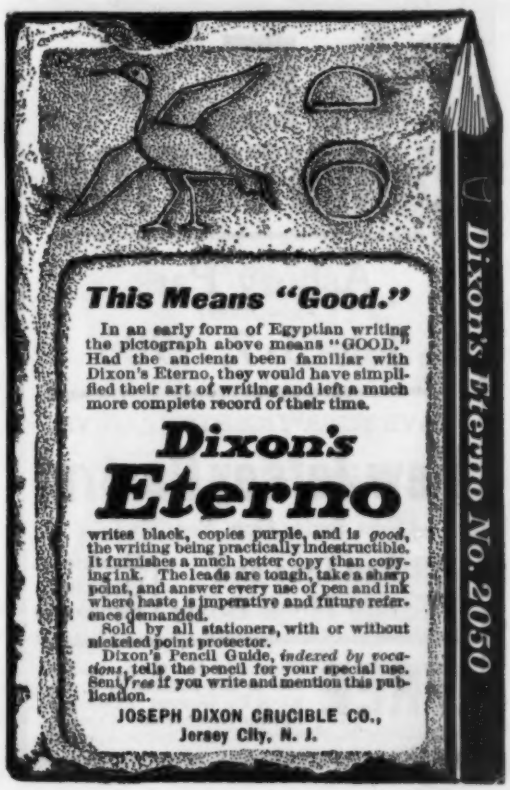
GEO. FROST CO. Makers Boston, Mass., U.S.A.

ALWAYS EASY

Mothers!
Mothers!!
Mothers!!!

Mrs. Winslow's Soothing Syrup

has been used for over SIXTY YEARS by MILLIONS of MOTHERS for their CHILDREN while TEETHING, with PERFECT SUCCESS. It SOOTHES the CHILD, SOFTENS the GUMS, ALLAYS all PAIN; CURES WIND COLIC, and is the best remedy for DIARRHŒA. Sold by Druggists in every part of the world. Be sure and ask for "Mrs. Winslow's Soothing Syrup," and take no other kind. Twenty-five cts. a bottle.



This Means "Good."

In an early form of Egyptian writing the pictograph above means "GOOD." Had the ancients been familiar with Dixon's Eterno, they would have simplified their art of writing and left a much more complete record of their time.

Dixon's
Eterno

writes black, copies purple, and is *good*, the writing being practically indestructible. It furnishes a much better copy than copying ink. The leads are tough, take a sharp point, and answer every use of pen and ink where haste is imperative and future reference demanded.

Sold by all stationers, with or without rubber point protector.

Dixon's Pencil Guide, *indexed by vocations*, tells the pencil for your special use. Sent *free* if you write and mention this publication.

JOSEPH DIXON CRUCIBLE CO.,
Jersey City, N. J.

ALWAYS
in SIGHT

Visible Writing
Perfect Construction
and Easy Manipulation
place

UNDERWOOD
TYPEWRITER

in a field by itself.

"A STANDARD—BEYOND COMPETITION."

Eventually **YOU** will use no other.

UNDERWOOD TYPEWRITER CO.
241 Broadway, New York.
Adapted for use with the
"Unit Book-keeping System."

"Y and E"

Free
On
Request—

A practical illustration of the "Y and E" Vertical System of correspondence filing.

¶ Shows exactly how compact and convenient this method is.

¶ Files ANYTHING FLAT, from letters to photo negatives.

¶ Want it?

YAWMAN & ERBE MFG. CO.
Phone: Central 2497
138-140 Wabash Avenue

N. E. A.
CONVENTION

Asbury Park
NEW JERSEY
July 3-7, 1905

HAVE YOUR TICKETS READ VIA

New Jersey Central

Two Routes From New York:

All Rail Line and Sandy Hook Boats | Shortest Quickest Picturesque

FREE Illustrated N. E. A. Folder sent to any address by C. M. BURT, General Passenger Agent, New Jersey Central, 143 Liberty St., New York City. Drop us a postal.

The Prospects of the Small College

By WILLIAM R. HARPER
President of the University of Chicago
12mo, paper; postpaid, 25 cents

The University of Chicago Press
CHICAGO, ILLINOIS
A Complete Catalogue of Publications Sent on Request

SPECIAL ANNOUNCEMENT

¶ An invitation is extended to any white merchant outside of New York city, or their representative, whose name appears in Bradstreet's or Dunn's Commercial Agency Book, also any white professional or educational person, to accept the hospitality of our Hotel for three days without charge. Usual rates, apartment with private bath $3.00 per day and up, without meals. Parlor, Bedroom and private bath $35.00 per week and up, with meals for two. New York Merchants and Editors are requested to call the attention of their Out of Town Buyers and subscribers to this advertisement.

GALLATIN HOTEL
70 W. 46th Street New York City

LIQUID GRANITE FOR FLOORS

IF you are having any trouble with the finish on your floors, or are not entirely pleased with their appearance, it is certain you have not used LIQUID GRANITE, the finest floor finish ever introduced.

It makes a finish so tough that, although the wood will dent under a blow, the finish will not crack or turn white. This is the highest achievement yet attained in a Floor Finish, and is not likely to be improved upon.

Finished samples of wood and instructive pamphlet on the care of natural wood floors sent free for the asking.

BERRY BROTHERS, Limited,

Varnish Manufacturers,

NEW YORK PHILADELPHIA CHICAGO ST. LOUIS
BOSTON BALTIMORE CINCINNATI SAN FRANCISCO

Factory and Main Office, DETROIT.
Canadian Factory, WALKERVILLE, ONTARIO

BAUSCH & LOMB Microscopes

Great Reduction in Prices

We have recently put in effect a new price list which greatly reduces the prices of several of our most durable Microscopes. Send for new Catalog.

Photographic Lenses

The success of a picture depends on the lense. Bausch & Lomb lenses do accurate work. Leading photographers everywhere use them. They add to the pleasure and profit of picture making. Send for Photographic Lens Catalog.

Bausch & Lomb Optical Co.

ROCHESTER, N. Y.

New York Chicago Boston Frankfort a. M., Germany

The

BALL BEARING

DENSMORE

Handsome Souvenir FREE to stenographers sending address and place of occupation

346-8 Broadway
NEW YORK

oes More Work

elights More People

eserves More Praise

Than Any Other Typewriter

FORTY YEARS of EDUCATION

in the Piano business

¶ We ought to know something about Pianos. Others think so, for we do the largest retail Piano business in the world.

¶ We are agents for 24 different makes of Pianos and have over 600 individual Pianos on our floors.

¶ The prospective purchaser can make comparisons here that would be impossible elsewhere. Then, too, we can meet your views in regard to price, for we have Pianos from $125.00 up.

¶ We sell Pianos on such terms of payment that no home need be without this necessary and artistic acquisition.

A Good New Piano for Rent
$4.00 per Month

¶ Let us send you our handsome Piano book. It is free for the asking. Write today.

Lyon & Healy

38 ADAMS STREET, CHICAGO

THE EUREKA REMOVABLE
MEMORANDUMS
INEXPENSIVE, HANDY, USEFUL

Fill up one book, simply slide out of cover and put in new tablet.....

ONE COVER WILL OUTWEAR 6 TABLETS

PRICES

Size	Complete Each	Extra Tablets Each
2½ x 4¼	.20	.05
2¾ x 4¾	.25	.08
3⅛ x 5⅛	.30	.10
3⅜ x 5⅛	.40	.10

Sent postpaid on receipt of price

S. D. CHILDS & CO.
WHOLESALE AND RETAIL STATIONERS
200 Clark Street CHICAGO

Through Pullman Service to Virginia

VIA THE FAMOUS

Big Four C. & O. Route

Leaves Chicago 1:00 p. m. daily.

"ONLY ONE NIGHT OUT."

All Meals in Dining Cars

All Big Four Trains stop at Illinois Central 63d St. Station, Chicago, within a few minutes' walk of the University of Chicago.

Only Railroad from Chicago and Peoria connecting in same depot at Cincinnati with trains of the

C. & O., Q. & C., L. & N. and B. & O. S. W. Railways

Chicago City Ticket Office
238 Clark Street 'Phone Harrison 4620
J. C. TUCKER, General Northern Agent.

THE
Morgan Park Academy
FOR BOYS

Is a constituent part of The University of Chicago, and is situated in the beautiful village of Morgan Park, eight miles from the city site of the University. This situation is most favorable, affording healthful surroundings and spaciousness of grounds.

The Faculty of the Academy consists of eleven men, all college graduates, well-trained in their departments.

The courses include Manual Training and meet the entrance requirements of all the leading colleges and technical schools.

Its seven buildings, all of brick and stone, consist of three dormitories, the new gymnasium, the library containing 6,000 volumes, the well-equipped science laboratory, and the recitation building.

The Academy's ideals are to develop the best possible manhood in its students and to this end all its discipline is directed. Especial effort is made to teach boys how to study and to form habits of work. The students' interests, athletic, literary, social, musical, and religious, are well sustained.

The expenses vary from $250.00 to $450.00 per year. Forty-five scholarships are given in recognition of excellence of effort.

THE FALL TERM BEGINS SEPTEMBER 20TH
FOR ILLUSTRATED CATALOGUE ADDRESS
DEAN WAYLAND J. CHASE, Morgan Park, Ill.

Say that YOURS is a

STECK

The "Old Reliable" Piano

and you will have convinced any competent critic of the soundness of your judgment.

Catalogue No. 10 free

Warerooms, 136 Fifth Ave., New York

When you were engaged

THE YOUNG LADY RECEIVED A BOX OF

Huyler's

ALMOST DAILY—

HOW OFTEN DOES YOUR WIFE NOW RECEIVE A BOX OF THESE DELICIOUS CONFECTIONS?

REPENT — AND MAIL YOUR ORDERS, AT SHORT INTERVALS, TO

Huyler's 863 BROADWAY / 508 FIFTH AVENUE NEW YORK

SEVENTEEN OTHER STORES & SALES AGENTS EVERYWHERE.

CANDIES SENT ANYWHERE BY MAIL & EXPRESS.

"FOLLOW THE FLAG"

WABASH

Summer Tours

Write today for a Free copy of WABASH Summer Tour Book—1905, outlining many very attractive summer vacation trips, with rates, etc.

Write us about any tour you may have in contemplation. We shall be glad to assist you.

C. S. CRANE, G. P. & T. Agent, ST. LOUIS.

F. A. PALMER, A. G. P. Agent, CHICAGO.

DENTACURA

TOOTH PASTE

Differs from the ordinary dentifrice in minimizing the causes of decay. Endorsed by thousands of Dentists. It is deliciously flavored, and a delightful adjunct to the dental toilet. In convenient tubes. For sale at drug stores, **25c.** per tube.

AVOID SUBSTITUTES

DENTACURA COMPANY,

Newark, N. J., U. S. A.

A New Edition

THE PLACE OF INDUSTRIES IN ELEMENTARY EDUCATION

By KATHARINE ELIZABETH DOPP, Ph.D.

278 pages cloth $1.00 net postpaid $1.11

Now Greatly Enlarged

AN entirely new chapter, seventy-two pages of text (chap. v. pp. 171-242), has been added. The Index has also been reconstructed and classifies all the additional material. The price has not been advanced: $1.00 net, postpaid $1.11.

An admirable work for Normal Schools

And Fully Illustrated

THE value of the book has been further enhanced by the addition of sixteen full-page illustrations. These are particularly appropriate because they nearly all show children actually engaged in industrial work.

Of great utility in teachers' reading

Outlines Practical Work

THE new material emphasizes the practical side of the work. The added chapter outlines a course in Colonial History, based upon the growth of Plymouth Colony; the illustrations are a complement to the work here suggested.

To be published June 1, 1905

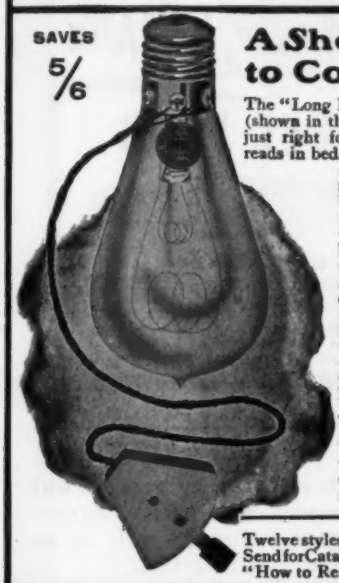
THIS book, recognizing the close relation between the stages of racial development and the definite periods of child-growth, advocates a much larger place in our educational system for the industries — whose development constitutes a chief characteristic of racial progress — than these have hitherto occupied. The volume is well written and has, in its shorter form, run through two editions.

The University of Chicago Press

CHICAGO and 156 Fifth Avenue NEW YORK

HYLO

SAVES 5/6



A Short Cut to Comfort

The "Long Distance" HYLO (shown in the illustration) is just right for the man who reads in bed. ¶ Cord snaps on like a glove fastener. Anybody can put it in place without tools. The portable switch turns the light high or low or entirely out. Switch lasts indefinitely. Only the lamp needs to be replaced when burned out. Cords can be any length desired.

Look for the name HYLO *and refuse imitations.*

Twelve styles of HYLO lamps. Send for Catalogue and booklet "How to Read Your Meter."

THE PHELPS COMPANY
108 STATE STREET DETROIT, U. S. A.

The PROOF of Remington Supremacy:

It outsells every other Typewriter

The REASON for Remington Supremacy:

It outworks and outwears every other Typewriter

Remington
Typewriter Company
New York and Everywhere

The University of Chicago Press

Educational and Scientific works printed in English, German, French, and all other modern languages.

Estimates Furnished

Address, 58th St. and Ellis Ave., Chicago

SPENCERIAN STEEL PENS.

The STANDARD AMERICAN BRAND
FOR OVER FIFTY YEARS

Have been subjected to the test of years and are recognized for all purposes *The Best.*

SPENCERIAN PEN CO.
349 Broadway, New York.

CHICAGO & ALTON RAILWAY
"THE ONLY WAY"

THE CHICAGO & ALTON
runs the largest passenger engines in the world
They keep the trains on time
Between Chicago, St. Louis, Kansas City and Peoria
GEO. J. CHARLTON, General Passenger Agent
CHICAGO, ILL.

Make Your Way of Working Light
FOR 25 YEARS THE STANDARD
100 STYLES
CALL ON YOUR DEALER AND GET A CATALOGUE
OR ADDRESS BOX 611
BLOOMSBURG, PA.
PAUL E. WIRT
FOUNTAIN PEN

PERRY & CO'S
ENGLISH MADE
STEEL PENS

ESTABLISHED 1894.
Samples and Prices from U. S. Sole Agents,
PERRY & CO.
349 Broadway, New York.

It costs you nothing to receive our announcements and other advertising matter. Simply ask to be placed on our mailing list.

The University of Chicago Press, Chicago, Ill.

Lectures on Commerce

A Book for Business Men

An interesting chapter

SOME RAILWAY PROBLEMS

By PAUL MORTON, Secretary of the Navy
Formerlp Vice-President of the Atchison, Topeka & Santa Fé Railway

is one of the five lectures on Railways included in this collection. The volume is edited by Henry Rand Hatfield, of the University of California. The other contributors on Railways are A. W. Sullivan, of the Illinois Central, on Railway Management and Operation; George G. Tunell, of the Chicago & Northwestern, on Railway Mail Service; E. D. Kenna, of the Atchison, Topeka & Santa Fé, on Railway Consolidation; Louis Jackson, of the Chicago, Milwaukee & St. Paul, on Railways as Factors in Industrial Development.

The other subjects treated in *Lectures on Commerce* are Higher Commercial Education, by J. Laurence Laughlin; The Steel Industry, by Franklin H. Head; Investments, by D. R. Forgan; The Comptroller of the Currency, the Methods of Banking, by James H. Eckels; Foreign Exchange, by H. K. Brooks; The History of the Art of Forging, by H. F. J. Porter; At Wholesale, by A. C. Bartlett; The Commercial Value of Advertising, by John Lee Mahin; The Credit Department of Modern Business, by Dorr A. Kimball; and Fire Insurance, by A. F. Dean.

Lectures on Commerce, 396 pages, 8vo, cloth, $1.50 net; $1.63 postpaid

THE UNIVERSITY of CHICAGO PRESS
CHICAGO and 156 Fifth Avenue NEW YORK

Free Guide to the Lewis AND Clark Exposition

We have just published a Lewis and Clark Exposition guide that's crowded with just the sort of information people want when planning the trip.

The guide is free for the asking. Write to-day. Our services in helping you to plan your trip are free, too.

Burlington Route

P. S. EUSTIS,
Pass'r Traffic Manager,
209 Adams Street,
Chicago.

P80

THE FOX TOUCH TYPEWRITER

Let us prove what we claim at our expense

There is only one way to prove anything about a typewriter, and that is an *actual test* of the machine itself *in your own office.*

That is what we want every possible purchaser of a Fox Typewriter to do before he buys.

When we say the Fox Typewriter can be operated with from 25 to 100 per cent less energy than any other typewriter, it doesn't mean anything to you unless we can show by this saving that it will enable you to reduce the cost of typewriting in your office, give you a better grade of work and save you a vast amount of worry about repairs. When we show you *that,* you are interested.

We have proved this to some of the most discriminating buyers in the country. Seventy-five per cent of our sales are made under just such circumstances.

If we can prove it to you, you want our machine.

Remember we *prove this* at our expense. All you have to do is say you are interested, no matter where you are.

Write us today.

Fox Typewriter Co.

Executive Office and Factory
560-570 Front St., GRAND RAPIDS, MICH.

Branches and Agencies in Principal Cities.

The New Hammond Typewriter

For All Nations and Tongues and used by All Classes of People.

THE BUSINESS MAN - Because the New Hammond is the Best Letter Writer, Manifolder and Tabulator.

THE SCIENTIFIC MAN - Because the Hammond has a practically unlimited range of service.

THE LITERARY MAN - Because the Hammond allows the use of several styles and sizes of type.

THE LINGUIST - - - Because on one Hammond machine more than twenty languages can be written.

THE LADIES - - - - Because the Hammond has a beautiful Script type and others in preparation.

EVERYBODY - *Because one Hammond will write anything in any style of type, language, or color of ink, on any size paper in any direction.*

THE HAMMOND TYPEWRITER COMPANY

69TH TO 70TH STS., AND EAST RIVER NEW YORK, N. Y.

BUFFALO LITHIA WATER

No Remedy of Ordinary Merit Could Ever Have Received Indorsations from Men Like These.

In Bright's Disease and Albuminuria of Pregnancy

Samuel O. L. Potter, A. M., M. D., M.R.C.P., *London, Professor of the Principles and Practice of Medicine and Clinical Medicine in the College of Physicians and Surgeons, San Francisco.*

Dr. Wm. H. Drummond, *Professor Medical Jurisprudence, Bishop's University, Montreal, Canada.*

Cyrus Edson, A. M., M. D., *Health Commissioner New York City and State, President Board of Pharmacy, New York City, Examining Physician Corporation Council, etc.*

John V. Shoemaker, M. D., LL. D., *Professor Materia Medica and Therapeutics, Medico-Chirurgical College, Philadelphia.*

Dr. George Ben. Johnston, *Richmond, Va., Ex-President Southern Surgical and Gynecological Association, Ex-President Medical Society of Va., and Professor of Gynecology and Abdominal Surgery, Medical College of Va.*

In Stone in the Bladder, Renal Calculi, and Inflammation of the Bladder

Dr. A. Gabriel Pouchet, *Professor of Pharmacology and Materia Medica of the Faculty of Medicine, Paris.*

Dr. J. T. LeBlanchard, *Prof. Montreal Clinic, SM., SN., V.U.*

Jas. M. Crook, A. M., M. D., *Professor Clinical Medicine and Clinical Diagnosis, New York Post Graduate Medical School.*

Louis C. Horn, M. D., Ph. D., *Professor Diseases of Children and Dermatology, Baltimore University.*

Dr. J. Allison Hodges, *President and Professor Nervous and Mental Diseases, University College of Medicine, Richmond, Va.*

In Gout, Rheumatism and Uric Acid Conditions

Dr. Robert Bartholow, M. A., LL. D., *Professor Materia Medica and General Therapeutics, Jefferson Medical College, Phila.*

Dr. I. N. Love, *New York City, Former Professor Diseases of Children, College of Physicians and Surgeons, and in Marion Sims College of Medicine, St. Louis.*

Hunter McGuire, M. D., LL. D., *Ex-President American Medical Association, Late President and Professor Clinical Surgery, University College of Medicine, Richmond, Va.*

Dr. Alexander B. Mott, *of New York, Professor of Surgery, Bellevue Hospital Medical College, Surgeon Bellevue Hospital.*

A pamphlet telling what these and many other of the leading medical men of the day say of the value of **BUFFALO LITHIA WATER** in the treatment of these diseases sent to any address. **BUFFALO LITHIA WATER** is for sale by the general Drug and Mineral Water trade.

PROPRIETOR BUFFALO LITHIA SPRINGS, VIRGINIA.

Used Round the World

Walter Baker & Co.'s

Chocolate

AND

Cocoa

The leader for 124 Years

LOOK FOR THIS TRADE-MARK

Grand Prize {World's Fair / St. Louis

Walter Baker & Co. Ltd.

Established 1780 Dorchester, Mass.

45 HIGHEST AWARDS IN EUROPE AND AMERICA

To insure a healthful home and prevent sickness, purify the cellar, closets, sinks, drains, and every spot where disease germs may lodge, with

Platt's Chlorides

THE HOUSEHOLD DISINFECTANT

An odorless, colorless liquid, which destroys foul odors and disease-breeding matter. When diluted with ten parts of water for household use, it costs less than 5 cents a quart. Sold everywhere in quart bottles.

PREPARED ONLY BY

HENRY B. PLATT, New York & Montreal

OUT O' DOORS

SUMMER PLEASURES are essentially out-of-door ones. All the active sports make the bath a luxury; add to its delights by using HAND SAPOLIO, the only soap which lifts a bath above a commonplace cleansing process, makes every pore respond, and energizes the whole body. It is a summer necessity to every man, woman, and child who would be daintily clean. Keeps you fresh and sweet as a sea breeze; prevents sunburn and roughness. Make the test yourself.

THE PERFECT PURITY of HAND SAPOLIO makes it a very desirable toilet article; it contains no animal fats, but is made from the most healthful of the vegetable oils. Its use is a fine habit.

HAND SAPOLIO is related to Sapolio only because it is made by the same company, but it is delicate, smooth, dainty, soothing, and healing to the most tender skin. Don't argue, Don't infer, Try it!

VOSE PIANOS

have been established over 50 YEARS. By our system of payments every family in moderate circumstances can own a VOSE piano. We take old instruments in exchange and deliver the new piano in your home free of expense.

Write for Catalogue D and explanations.

VOSE & SONS PIANO CO., 160 Boylston St., Boston, Mass.